XXIV QUARK MATTER
DARMSTADT 2014

J/ψ PRODUCTION IN p-Pb COLLISIONS WITH ALICE AT THE LHC

ALICE

Javier Martin Blanco
for the ALICE collaboration

Subatech
cnrs
UNIVERSITÉ DE NANTES

Quark Matter 2014, Darmstadt 20/05/2014

OUTLINE

- Motivation
- Analysis
- Results
  - Forward-y to backward-y ratio (R_{FB})*
  - Nuclear modification factor (R_{pPb})*
  - R_{pPb} p_{T} dependence
  - Q_{pPb} vs ZN event activity **New ALICE preliminary**
  - Relative yields vs charged particle multiplicity **New ALICE preliminary**
  - Relative $\langle p_{\mathrm{T}} \rangle$ vs charged particle multiplicity **New ALICE preliminary**
- Conclusions

* Forward-y and backward-y results are **published results** from:
J/ψ production and nuclear effects in p-Pb collisions at $\sqrt{s_{NN}}$ *=5.02 TeV*, JHEP 02 (2014) 073

MOTIVATION

Why study p-Pb collisions?

- Understand cold nuclear matter effects
- Necessary to disentangle hot (QGP related) and cold nuclear matter effects in Pb-Pb collisions

[1] e.g. Phys. Rev. C 88(2013) 047901
[2] e.g. arXiv:1205.1554 (2012)
[3] e.g. Phys. Rev. Lett. 109(2012)122301
[4] e.g. Nucl. Phys. A700(2002)539

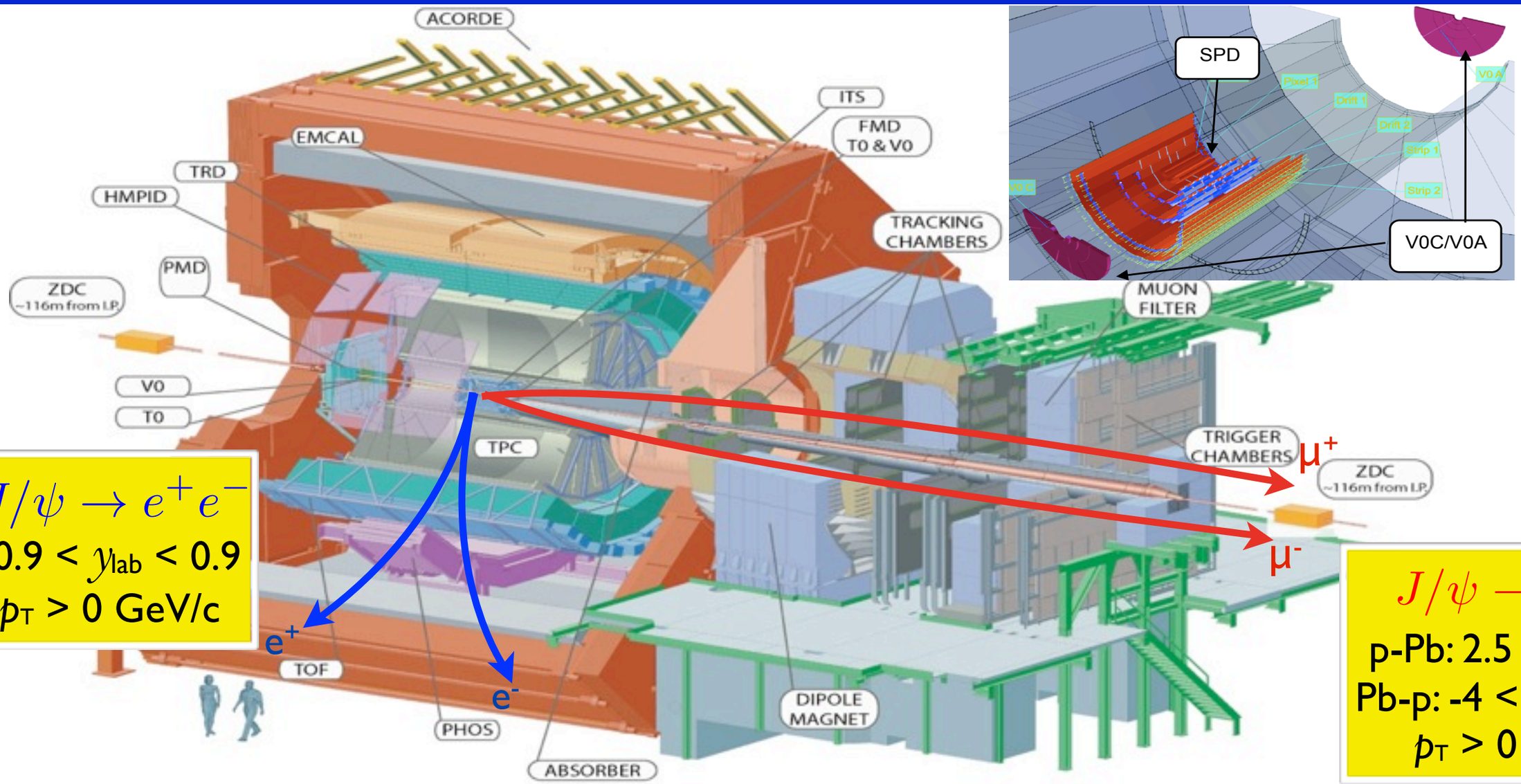
Cold nuclear matter effects:

- Initial state effects: **Gluon shadowing** [1] (or **saturation** [2])
  - Shadowing: gluon pdf in a nucleus $\neq$ in a nucleon (saturation: when energy is high enough, gluons start to recombine with each other)

    Expected to be significant at LHC energies, depending on the kinematic domain
- **Coherent energy loss** [3]
  - The medium-induced gluon radiation modifies the initial-state gluon kinematics and affects the final-state $c\bar{c}$ pair
- Final state effects: **Nuclear absorption** [4]
  - Destruction of pre-resonant or final state J/ψ by collisions with nucleons

    Should be negligible at the LHC since crossing-times are smaller than quarkonium formation times.

THE ALICE DETECTOR



$J/\psi \rightarrow e^+e^-$

-0.9 < y_{lab} < 0.9

p_T > 0 GeV/c

$J/\psi \rightarrow \mu^+\mu^-$

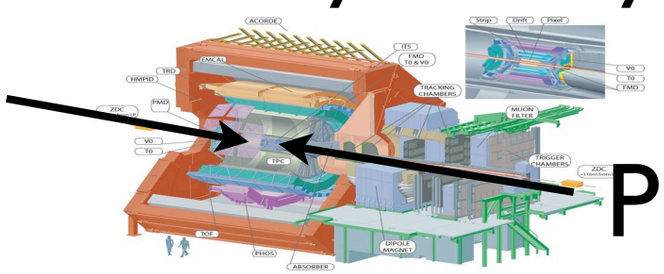
p-Pb: 2.5 < y_{lab} < 4

Pb-p: -4 < y_{lab} < -2.5

p_T > 0 GeV/c

LHC beam asymmetry → $|\Delta y|_{cms} = 0.5Log(Z_{Pb}A_p/Z_pA_{Pb}) = 0.465$

P

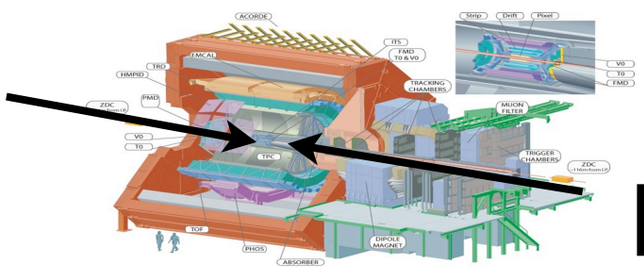


Pb

Common range:

2.96 < | y_{cms}| < 3.53

Pb



P

2.03 < y_{cms} < 3.53 (-1.37 < y_{cms} < 0.43)

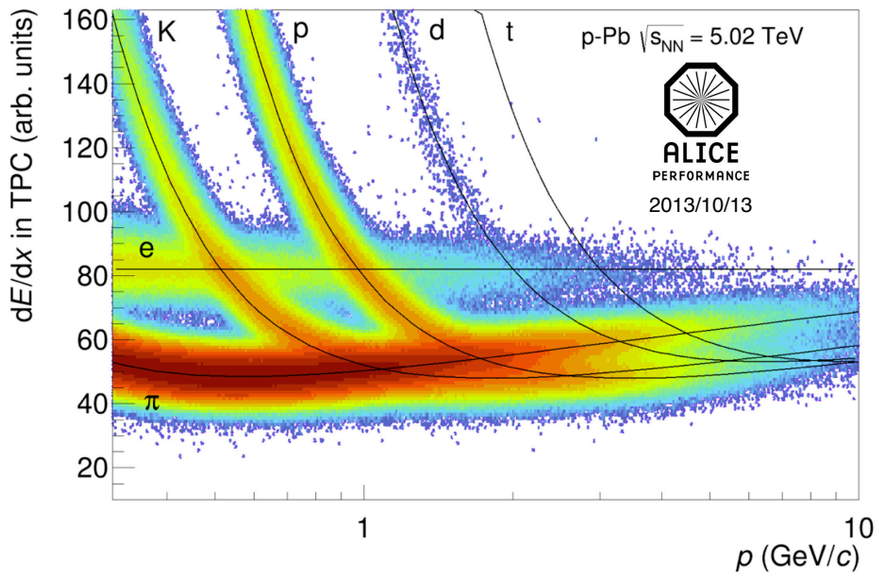
$1.8\cdot10^{-5}$ < $x_{Bjorken}$ < $8.1\cdot10^{-5}$ ($0.4\cdot10^{-3}$ < $x_{Bjorken}$ < $2.4\cdot10^{-3}$)

-4.46 < y_{cms} < -2.96

$1.2\cdot10^{-2}$ < $x_{Bjorken}$ < $5.3\cdot10^{-2}$

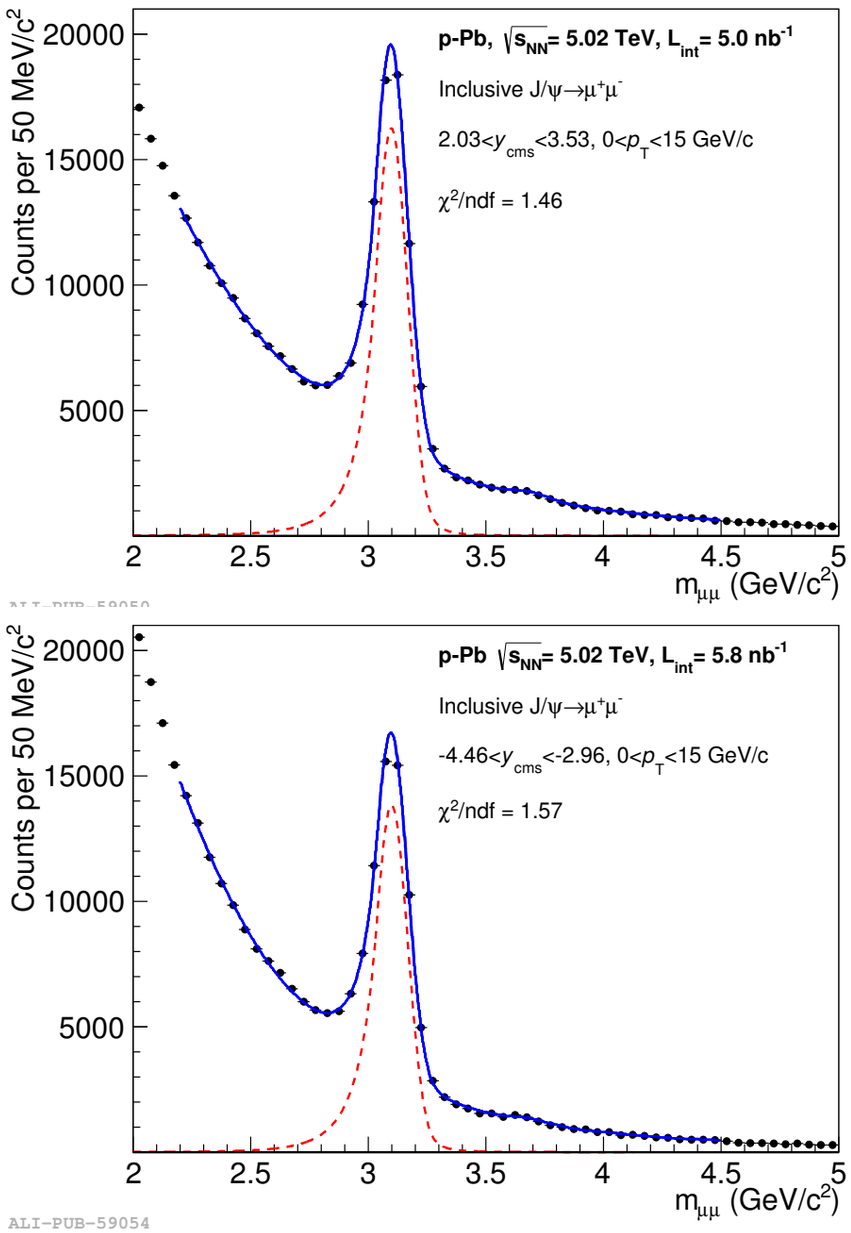
DATA SELECTION

- **Event selection**
  - Minimum Bias (MB) trigger: Coincidence of the two VZERO ($2.8 < \eta^{lab} < 5.1$ and $-3.7 < \eta^{lab} < -1.7$)
  - Rejection of beam-gas and electromagnetic interactions
  - SPD used for vertex determination and charged particle multiplicity measurement
  - ZDC used for event activity determination (in particular ZN)
  - $|Z_{vertex}| < 10$ cm (for dielectron analysis and for charged particle multiplicity measurement)
- **Dimuon trigger**
  - MB & two opposite sign muon tracks in the trigger chambers
- **Dimuon analysis cuts**
  - Muon trigger matching
  - $-4 < \eta_{\mu}^{lab} < -2.5$
  - 17.6 cm $< R_{abs} < 89.5$ cm (R_{abs} is the track radial position at the end of the absorber)
  - $2.5 < y_{\mu\mu}^{lab} < 4$
- **Dielectron trigger**
  - MB
- **Dielectron analysis cuts**
  - Track quality cuts
  - $-0.9 < \eta_{e}^{lab} < 0.9$ and $p_T > 1$ GeV/c
  - Rejection of tracks from photon conversion
  - TPC electron identification

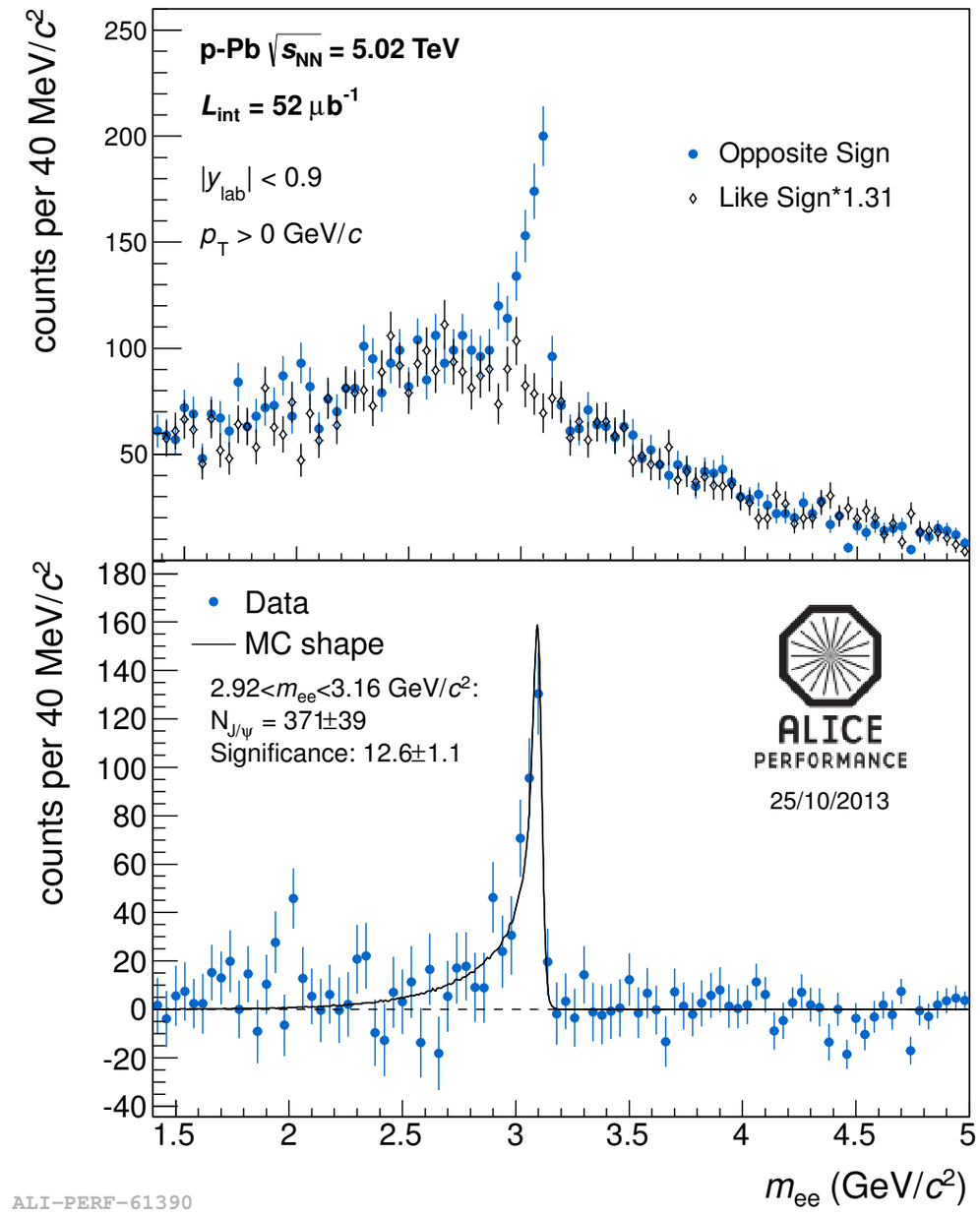


SIGNAL EXTRACTION

forward and backward rapidity



midrapidity



- **Background:** variable-width Gaussian or polynomial x exponential parametrization.
- **Resonance:** Crystal Ball or pseudo-gaussian function with tails parameters tuned on MC

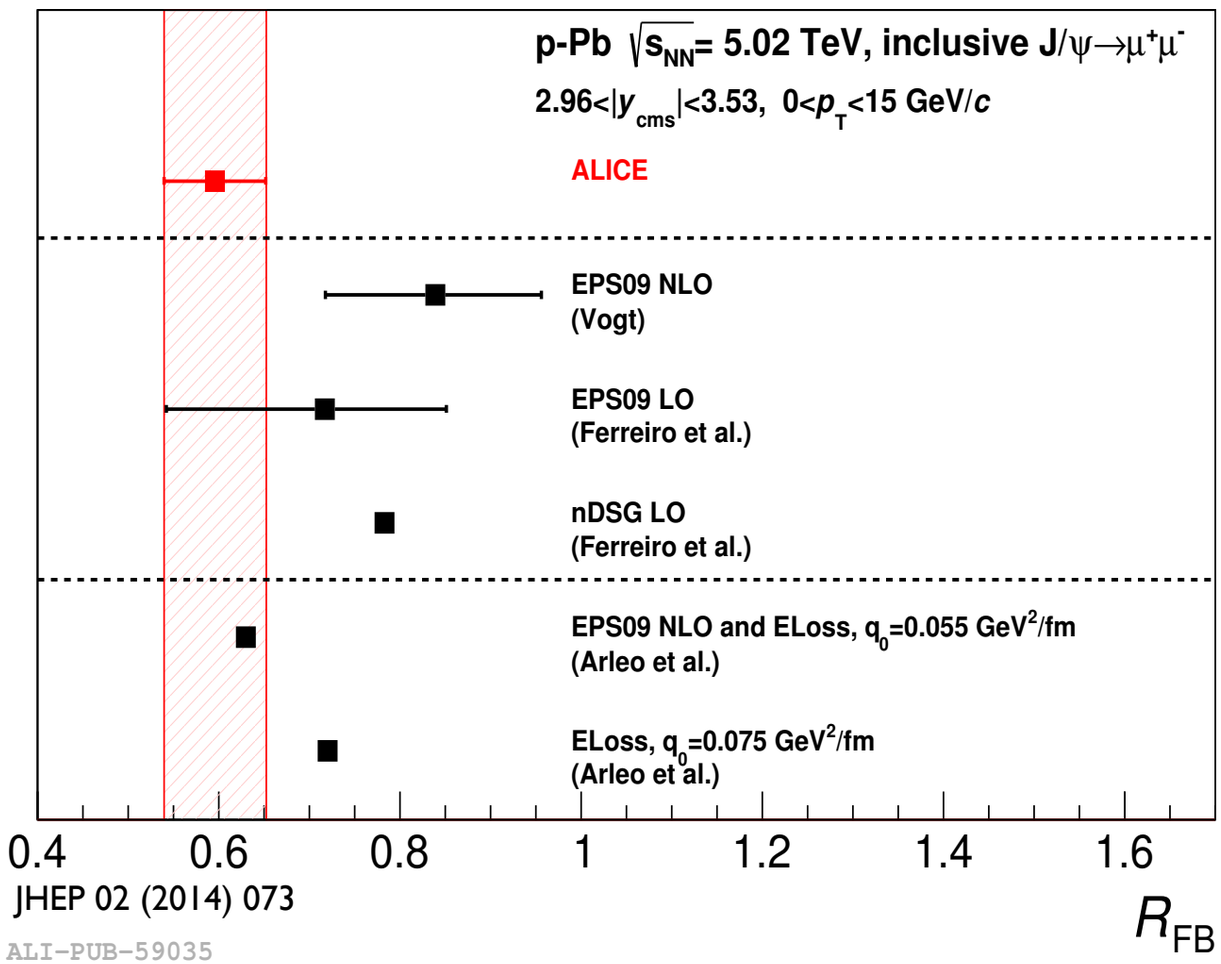
- **Background:** subtracted using normalized like-sign pair distribution or parametrized using ratio of polynomial functions.
- **Resonance:** bin by bin counting in 2.92-3.16 GeV/c^2

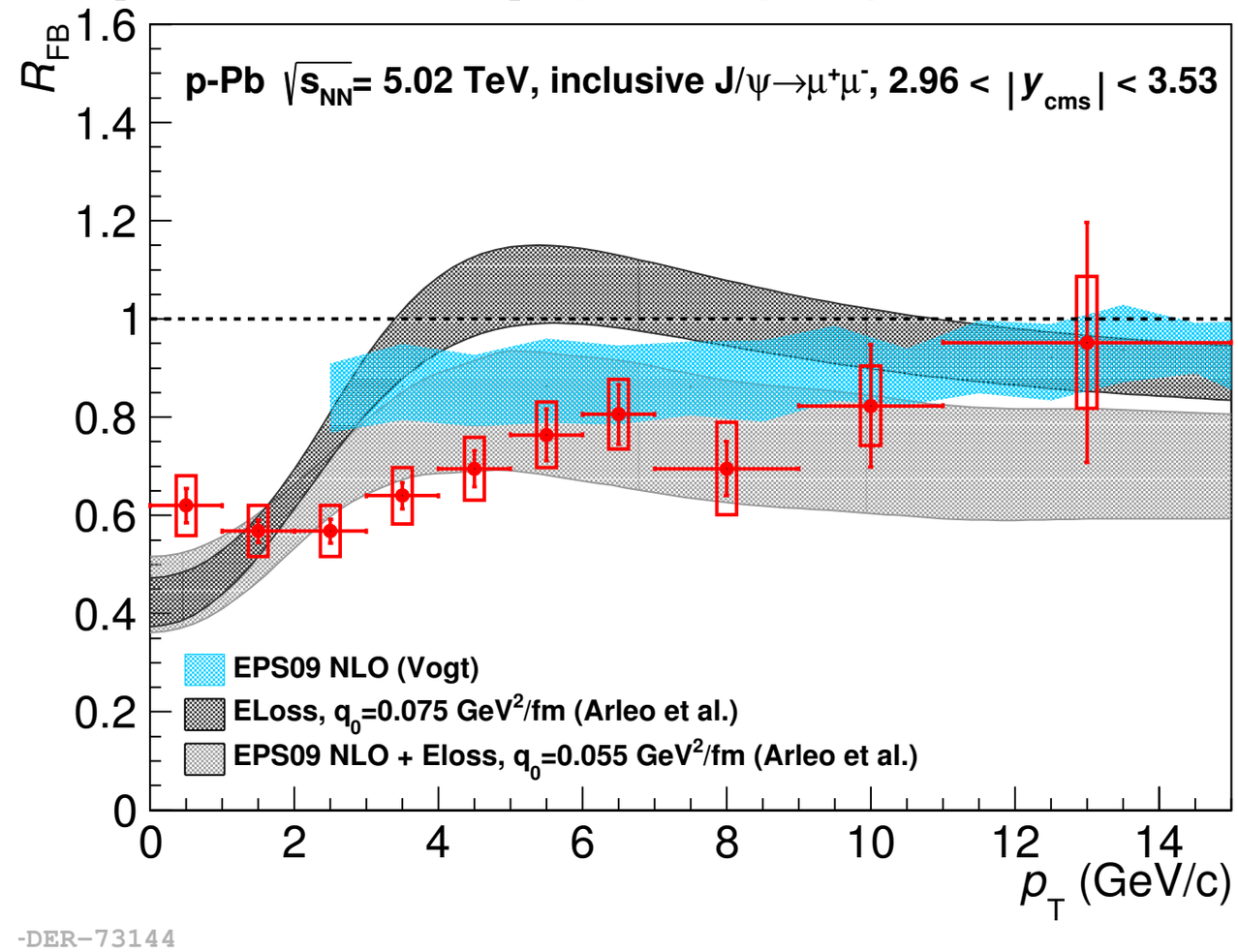
INTEGRATED AND p_T DIFFERENTIAL R_{FB}

$$R_{FB}^{J/\psi} = \frac{Y^{Forward}_{J/\psi\to\mu^+\mu^-}}{Y^{Backward}_{J/\psi\to\mu^+\mu^-}}$$

Independent of nuclear thickness (T_{pPb}) and pp cross section

Computed in the **y_{cms} range common to p-Pb and Pb-p** (**2.96 < $|y_{cms}|$ < 3.53**)





- Pure shadowing slightly overestimates data
- Shadowing with energy loss in good agreement with data

- Dependence with p_T is observed
- The suppression is stronger at low p_T

- Data are consistent with shadowing + energy loss models

R_{pPb} MEASUREMENT

$$R_{pPb}^{J/\psi} = \frac{Y_{pPb}^{J/\psi}}{< T_{pPb} > \sigma_{pp}^{J/\psi}}$$

- Computed in the **full acceptance windows** **(2.03 < y_{cms} < 3.53 and -4.46 < y_{cms} < -2.96)**

- **Nuclear thickness function**

  $<T_{pPb}>$ = 0.0983 ± 0.0034 mb^{-1}

- **pp reference cross-section**: no measurement at required energy, need to interpolate. Two step procedure in both analyses.
  - Dimuon analysis [1]:

    1) $\sqrt{s}$ interpolation: performed bin-per-bin in rapidity (or p_T) using available ALICE pp results at 2.76 and 7 TeV

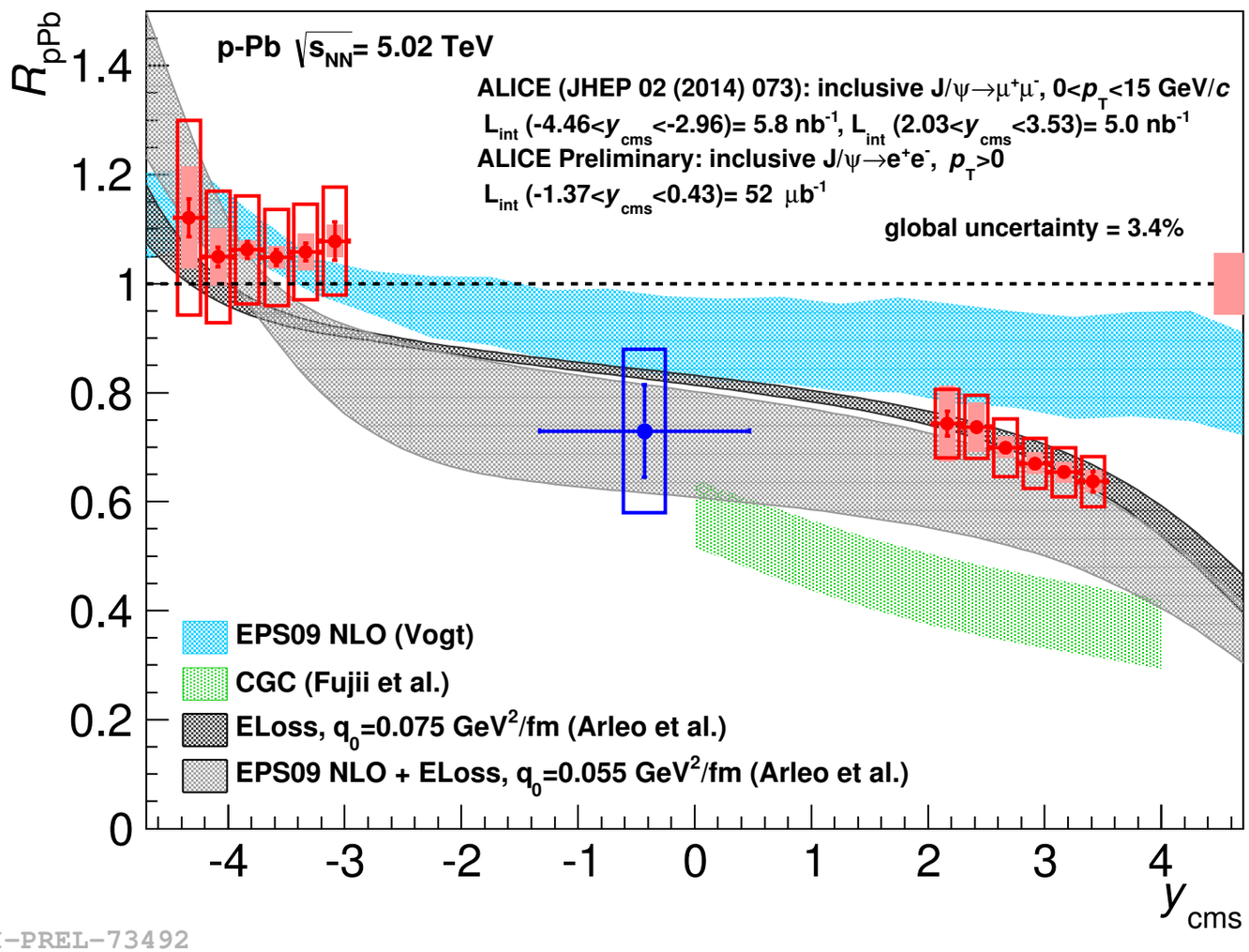
    2) Further rapidity extrapolation: due to rapidity shift, p-Pb y_{cms}-range lies slightly outside the pp y_{cms}-range
  - Dielectron analysis:

    1) $\sqrt{s}$ interpolation: performed using available PHENIX, CDF and ALICE results at $y \approx 0$

    2) p_T dependence: phenomenological scaling inspired by reference [2]

[1] ALICE-PUBLIC-2013-002
[2] arXiv: 1103.2394

R_{pPb} vs RAPIDITY

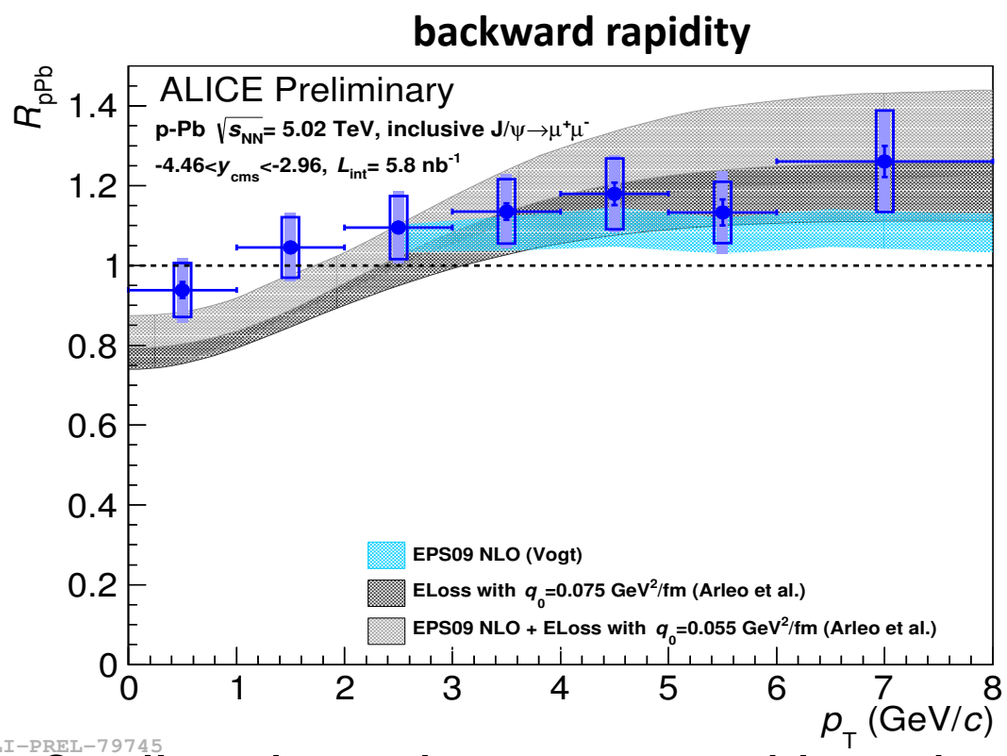


Systematic uncertainties:
- Colored boxes : uncorrelated
- Shaded areas : partially correlated
- Box around unity : fully correlated

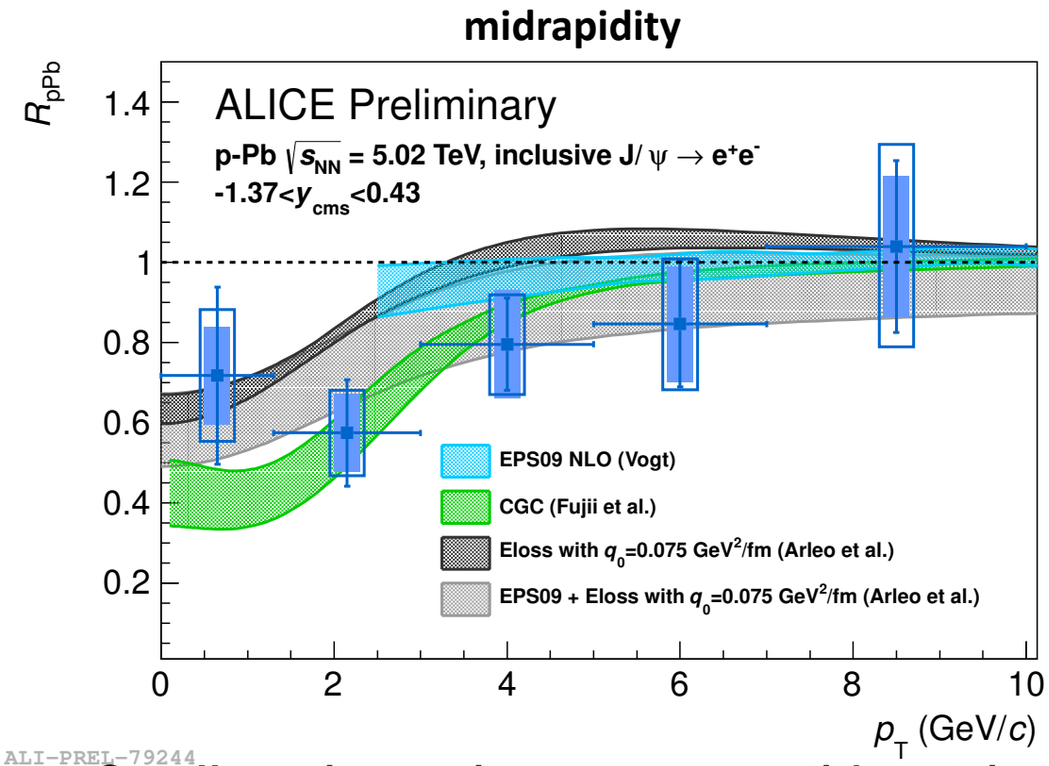
- Strong suppression at mid and forward rapidity
- No suppression at backward rapidity

- Data are consistent with models including shadowing and/or energy loss
- Color Glass Condensate (CGC) inspired model underestimates the data

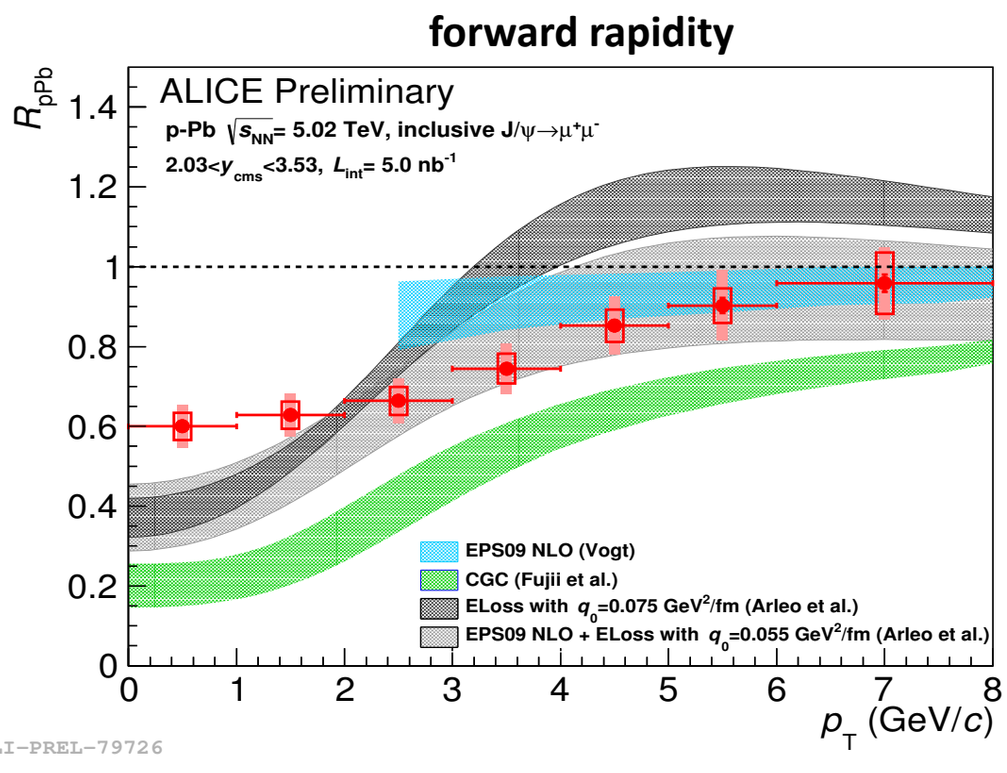
R_{pPb} vs p_T



- Small p_T dependence, compatible with unity



- Small p_T dependence, compatible with unity for $p_T \gtrsim 3$ GeV/c



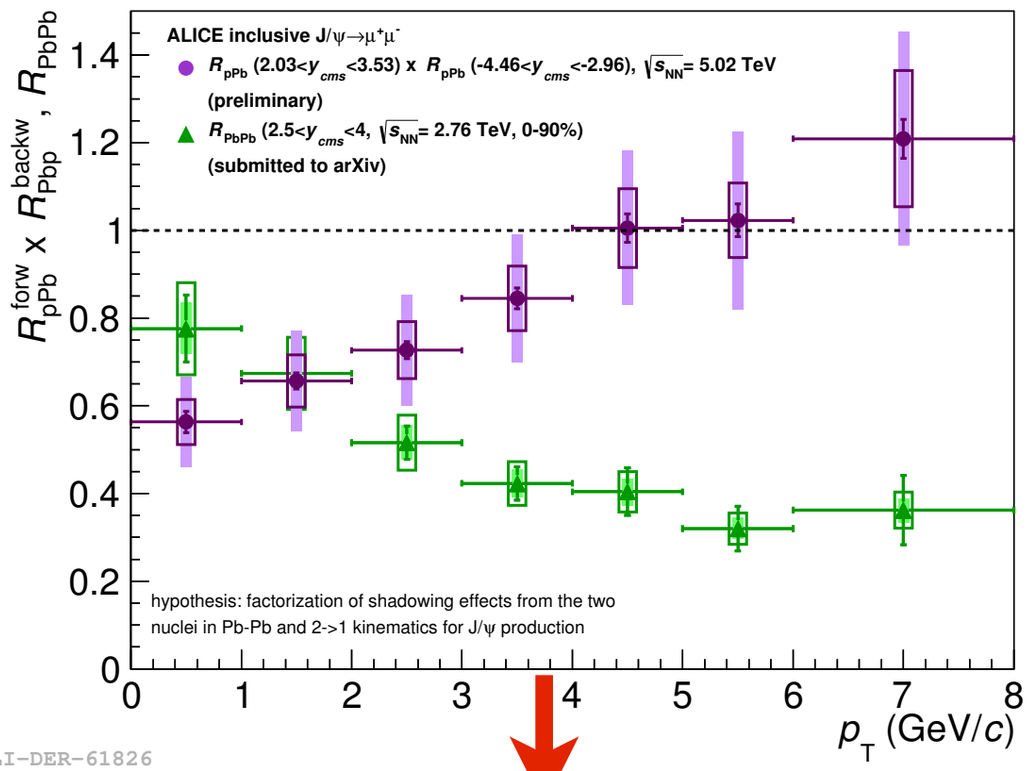
- Increases with p_T, compatible with unity for $p_T \gtrsim 5$ GeV/c

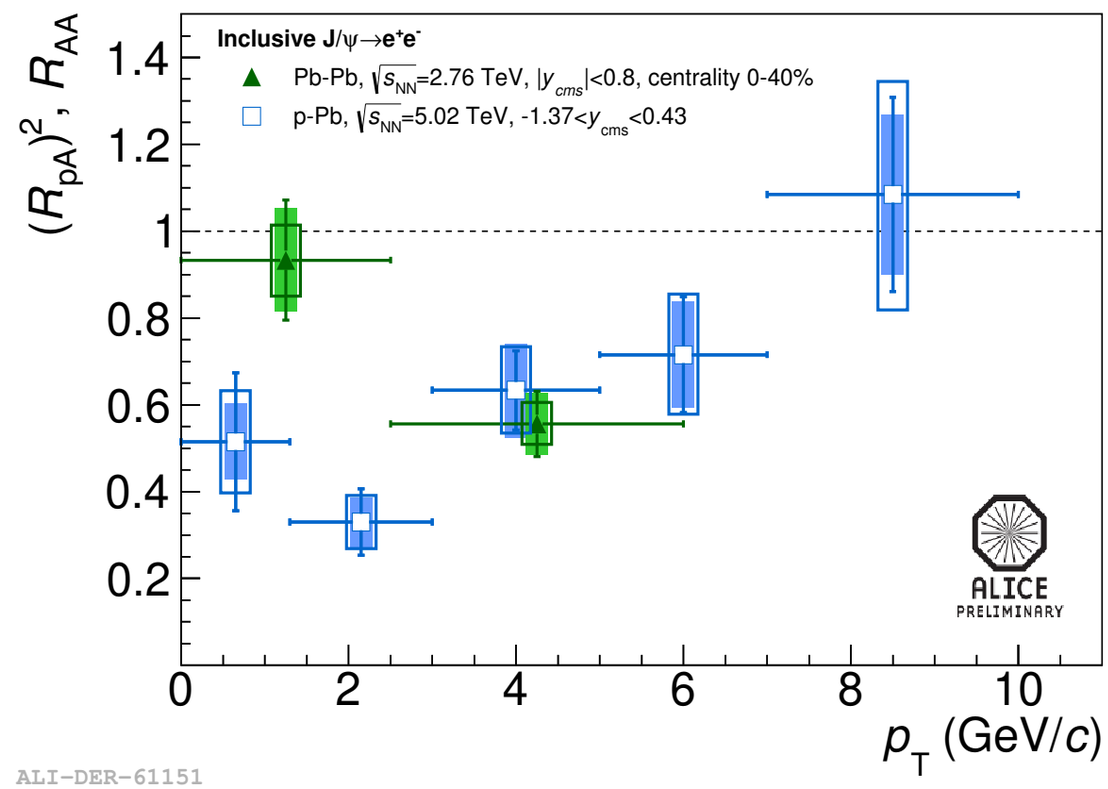
- Data are consistent with shadowing only model (calculation for p_T > 2.5 GeV/c)
- Coherent energy loss overestimates suppression at forward rapidity and low p_T
- CGC overestimates suppression at forward rapidity

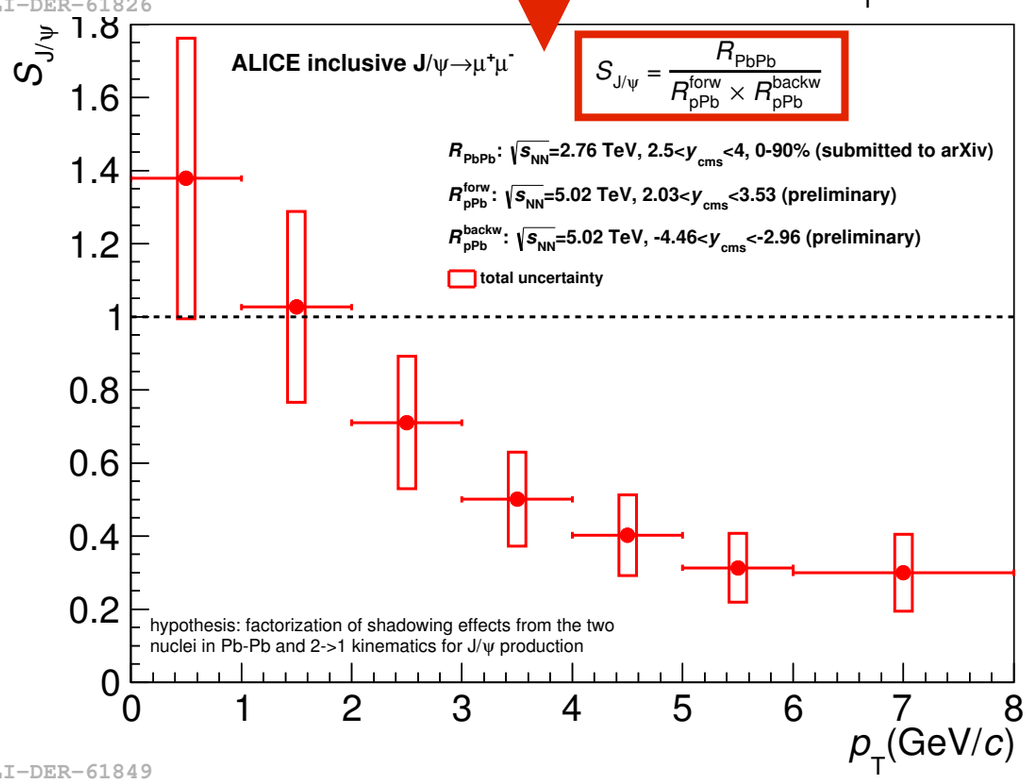
COLD NUCLEAR MATTER EFFECTS IN Pb-Pb

Assumptions:
- Production mechanism: $g + g \rightarrow J/\psi$
- CNM effects factorize in p-nucleus and are dominated by shadowing

See Pb-Pb talk by J. Book





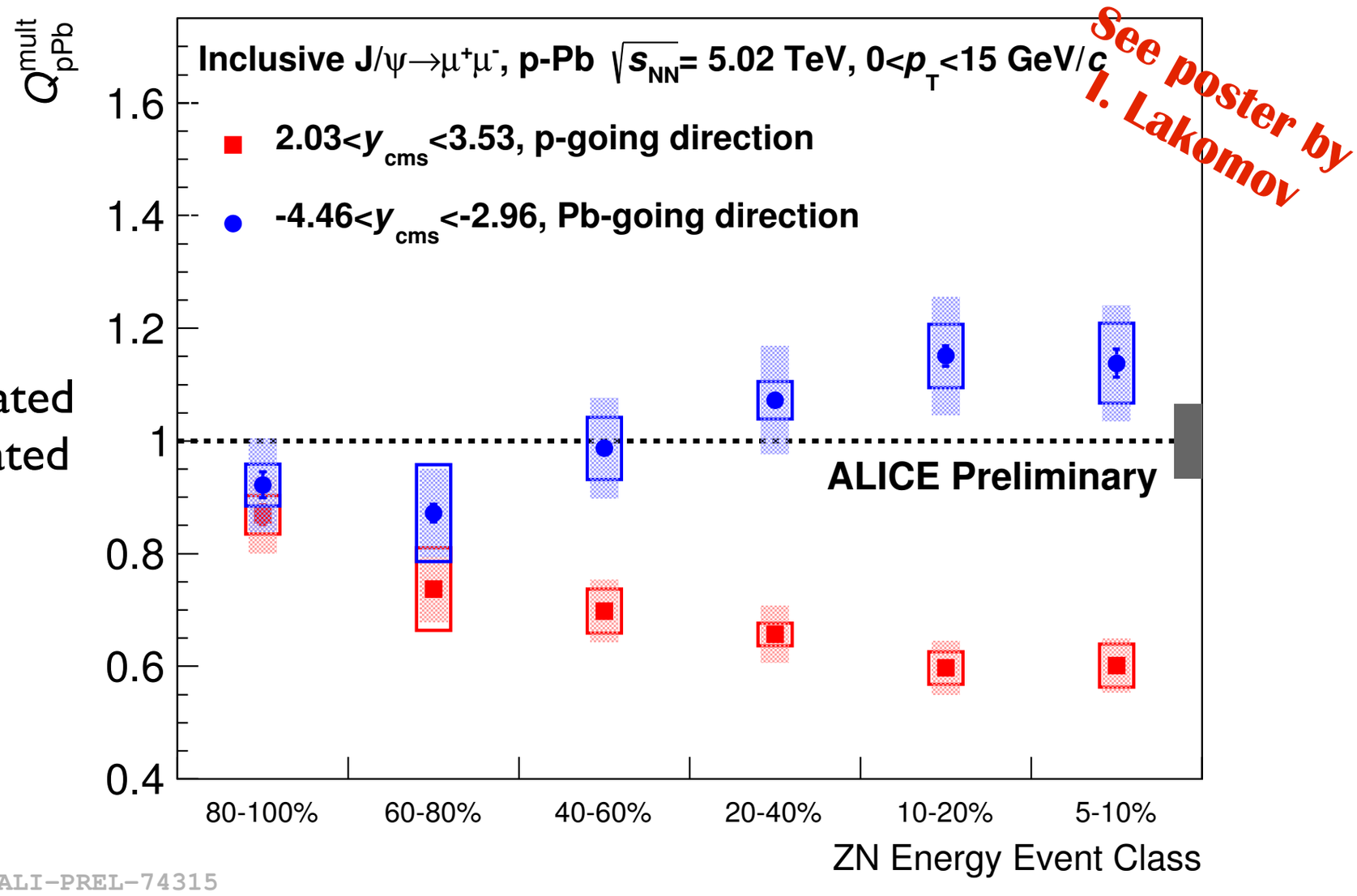


- Increase of $S_{J/\psi}$ at low p_T (observation that favors recombination scenario in Pb-Pb)
- Strong suppression at high p_T

p_T-INTEGRATED Q_{pPb} vs EVENT ACTIVITY

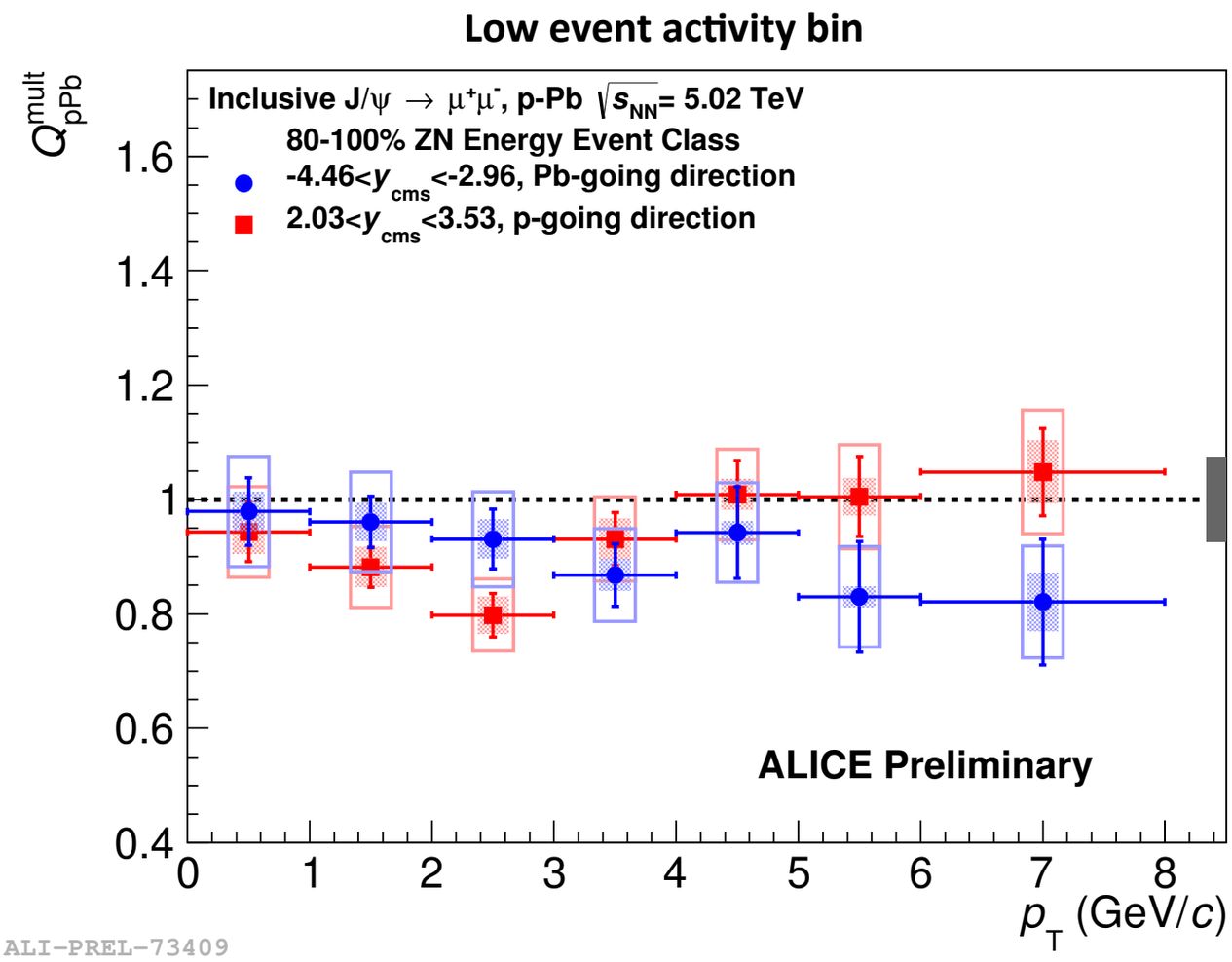
Q_{pPb} has the same definition of R_{pPb}. A different notation is used due to potential biases in the event activity estimator (ZN energy) not related to nuclear effects

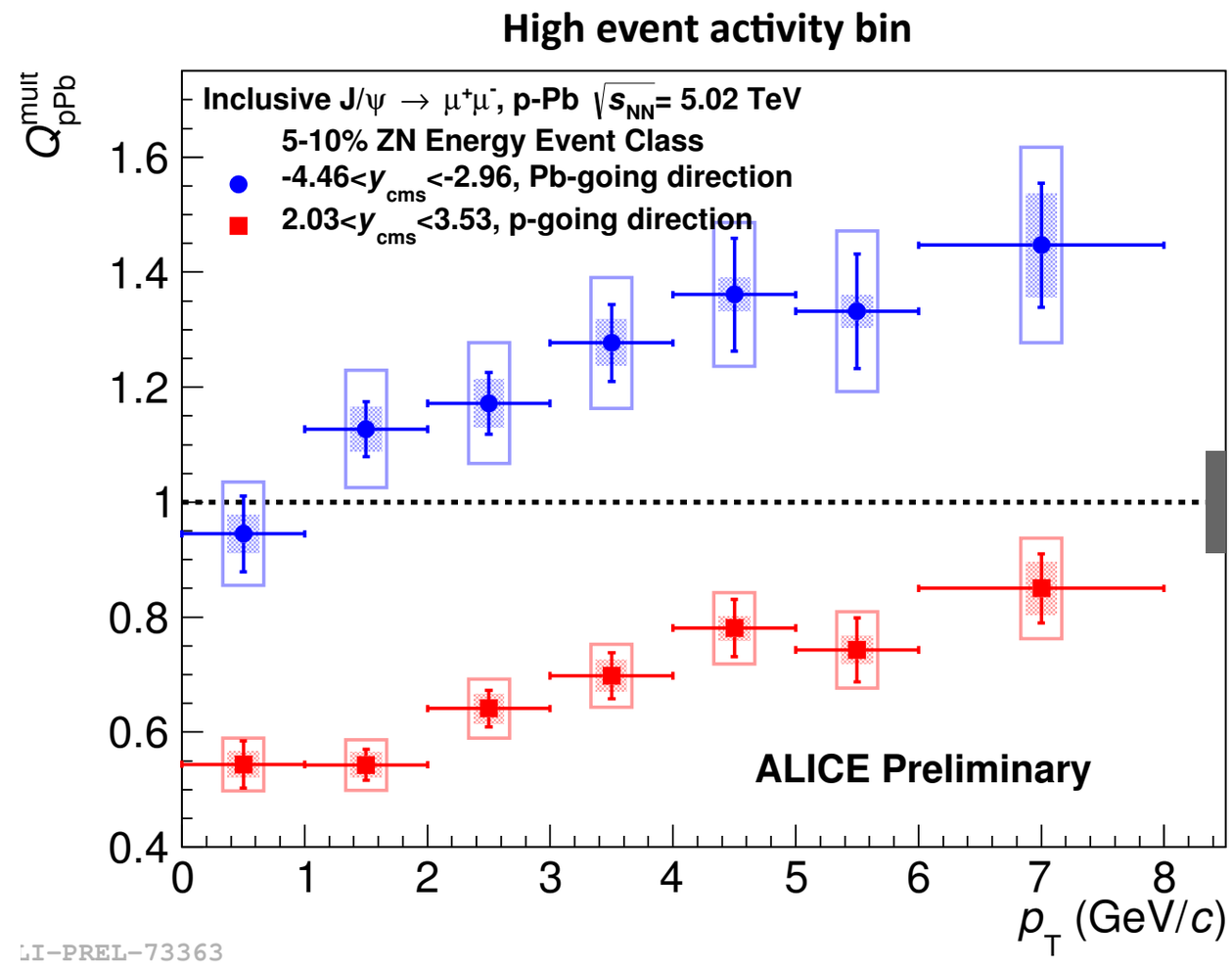
Systematic uncertainties:
- Colored boxes : uncorrelated
- Shaded areas : partially correlated
- Box around unity : fully correlated



- Decrease of Q_{pPb} from low to high event activity at forward rapidity is observed
- Q_{pPb} is consistent with unity at backward rapidity

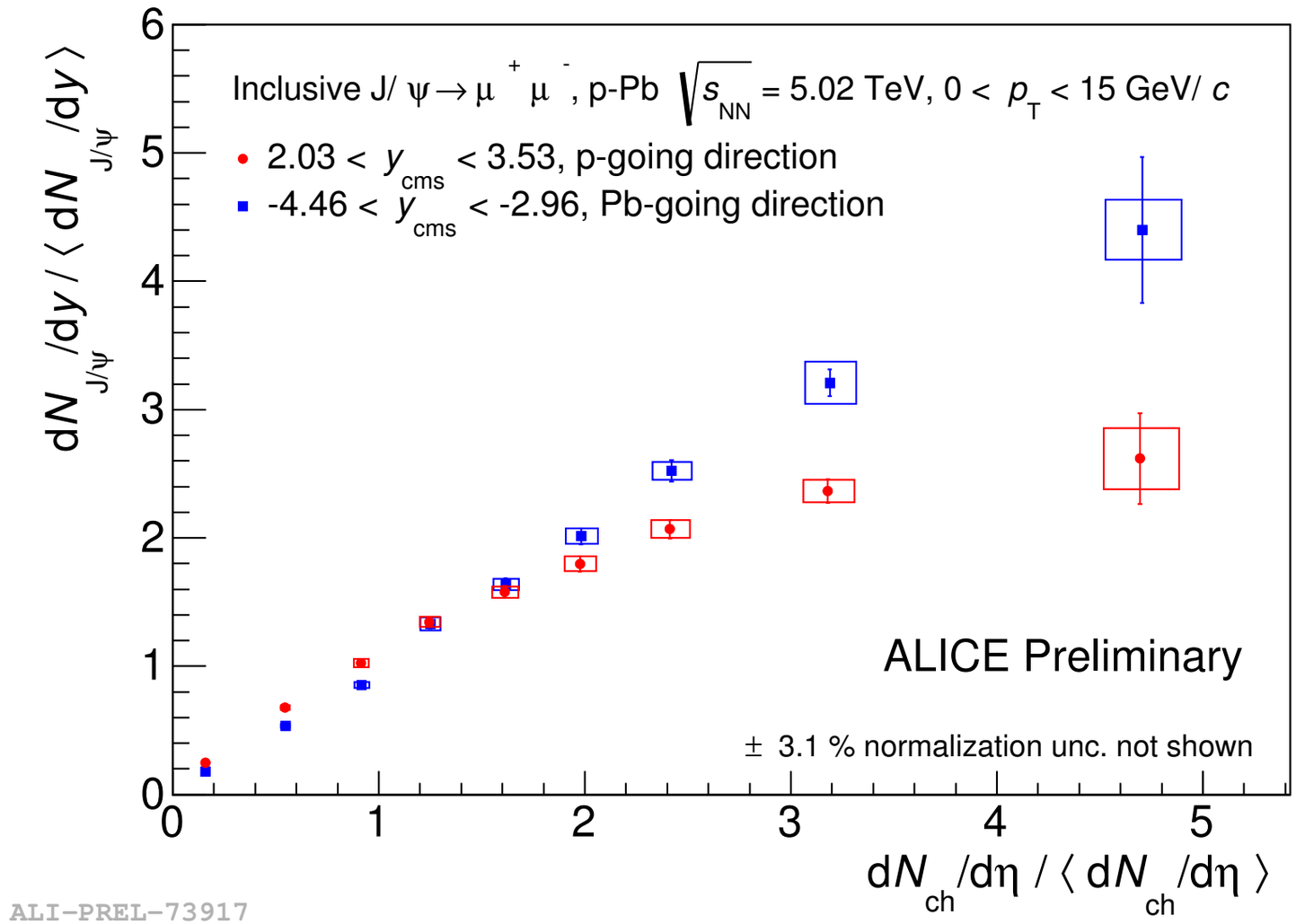
Q_{pPb} vs p_T : EVENT ACTIVITY DEPENDENCE





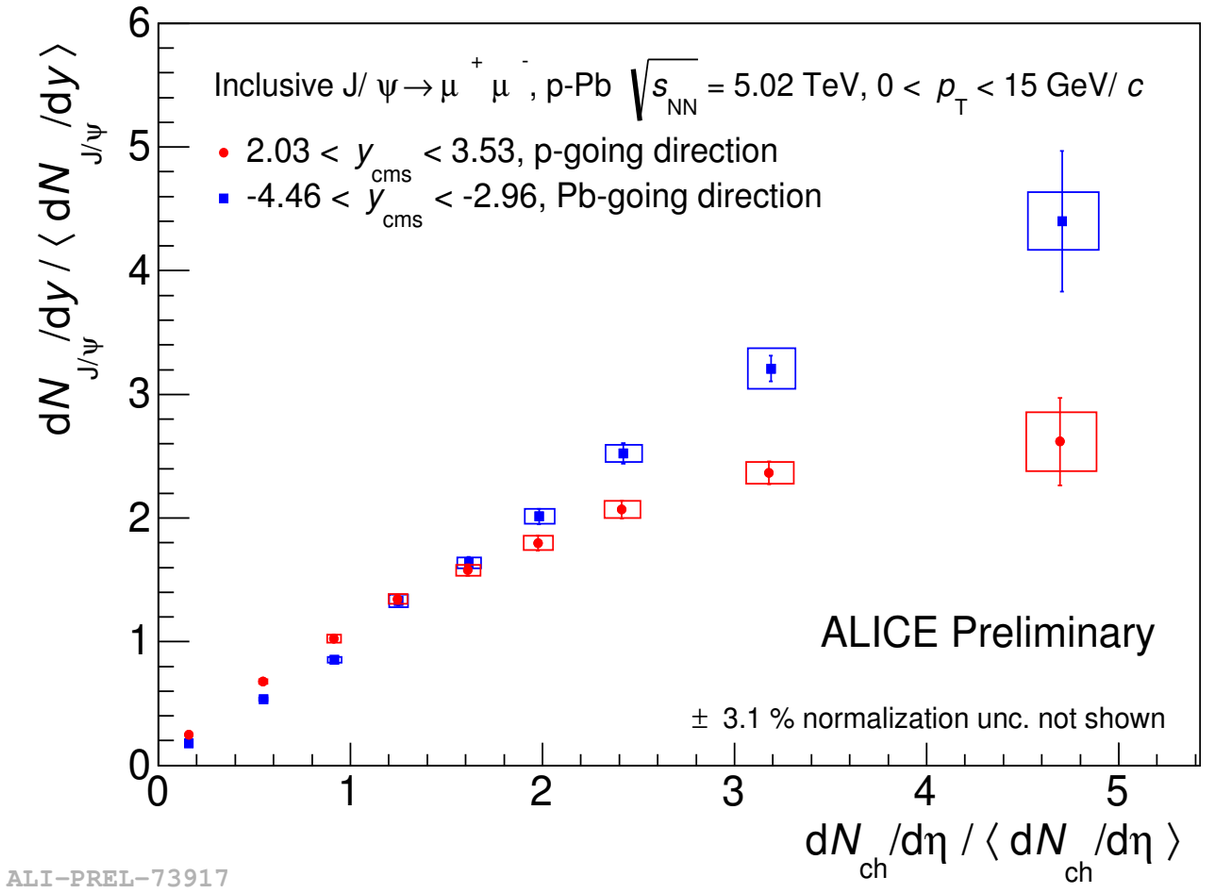
- **Increase** of Q_{pPb} for increasing event activity at **backward** rapidity. A clear p_T dependence is also observed at high event activity, with a stronger enhancement at high p_T
- **Decrease** of Q_{pPb} for increasing event activity at **forward** rapidity. A clear p_T dependence is also observed at high event activity, with a stronger suppression at low p_T
- For increasing event activity the difference between forward and backward rapidity results becomes much stronger

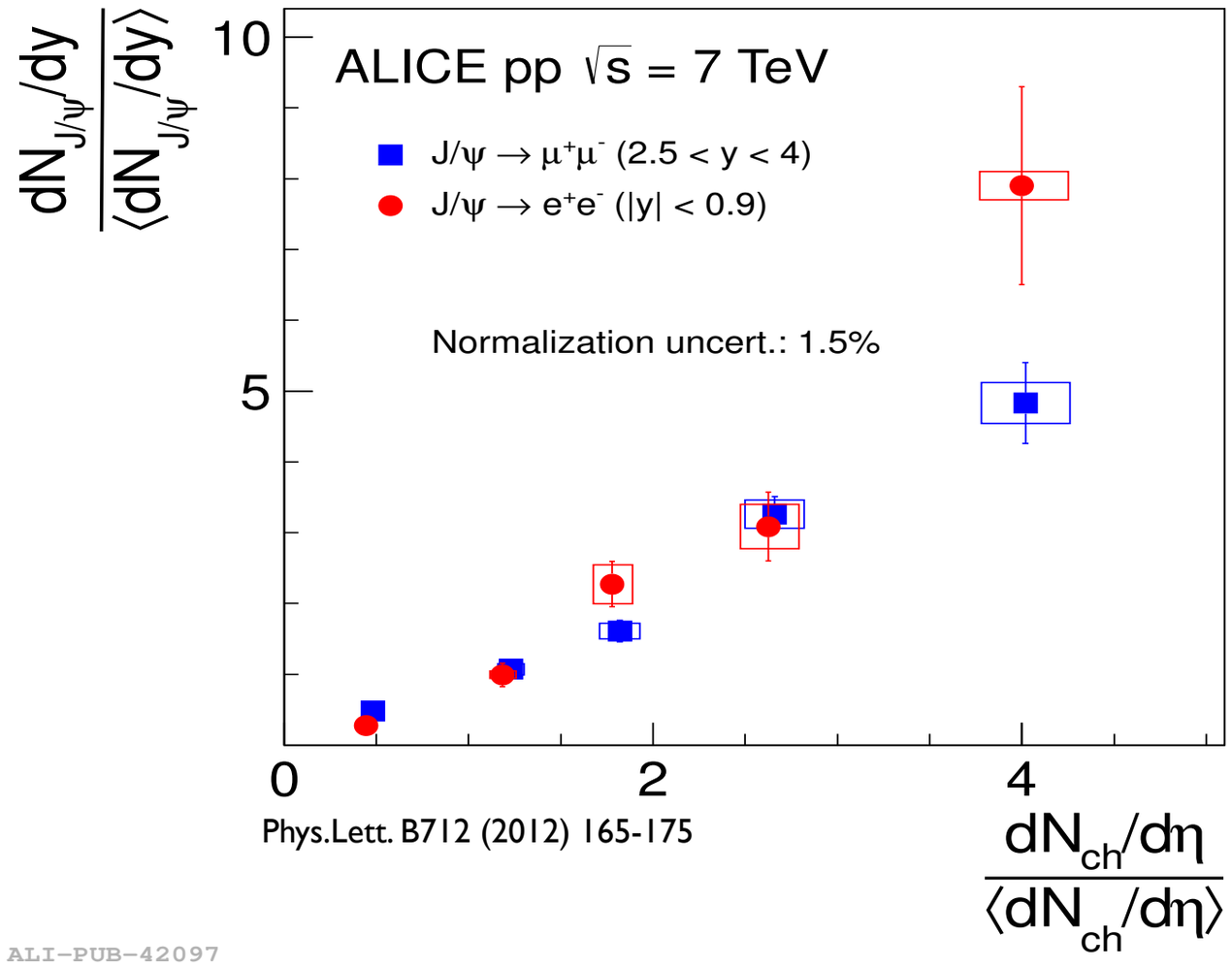
RELATIVE YIELD vs MID-y RELATIVE MULTIPLICITY



- **Strong increase** of relative J/ψ yields at forward and backward rapidity with relative multiplicity

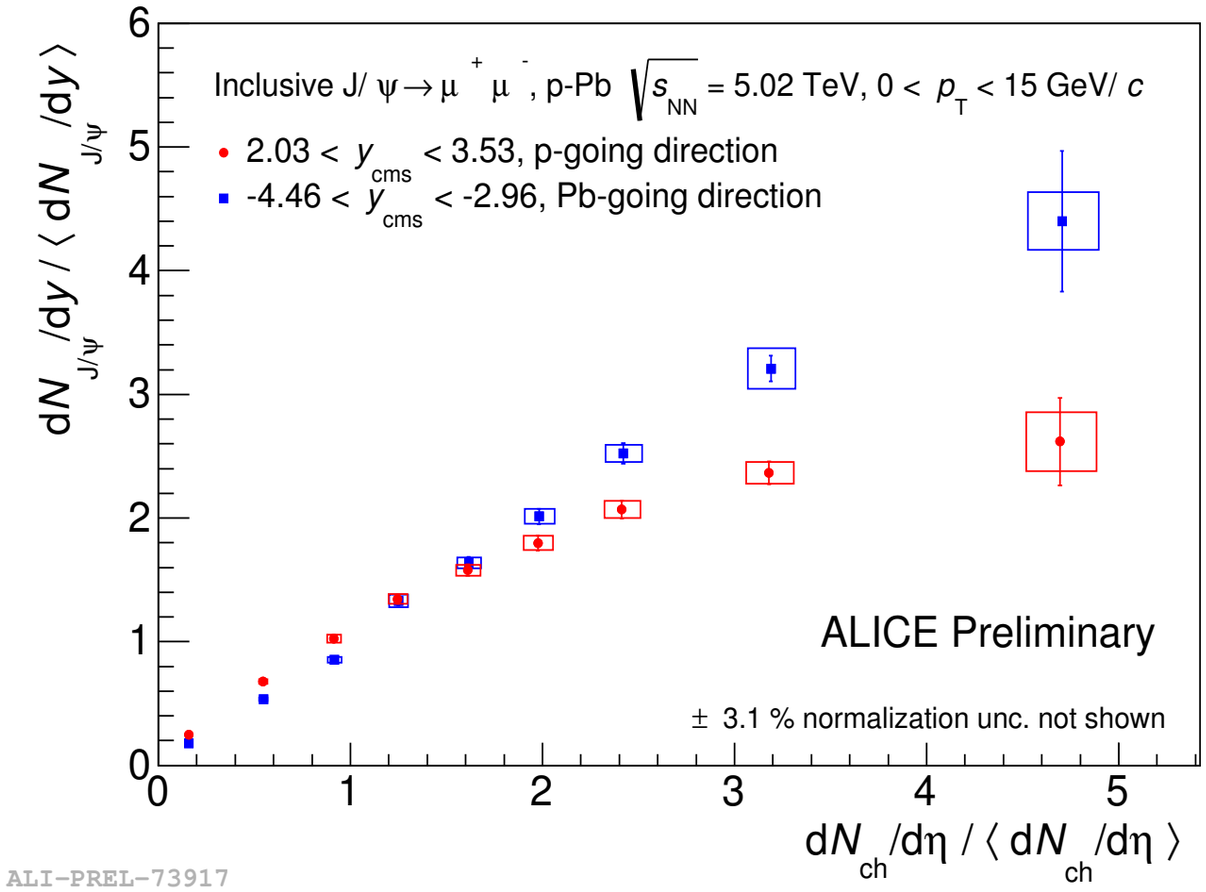
RELATIVE YIELD vs MID-y RELATIVE MULTIPLICITY



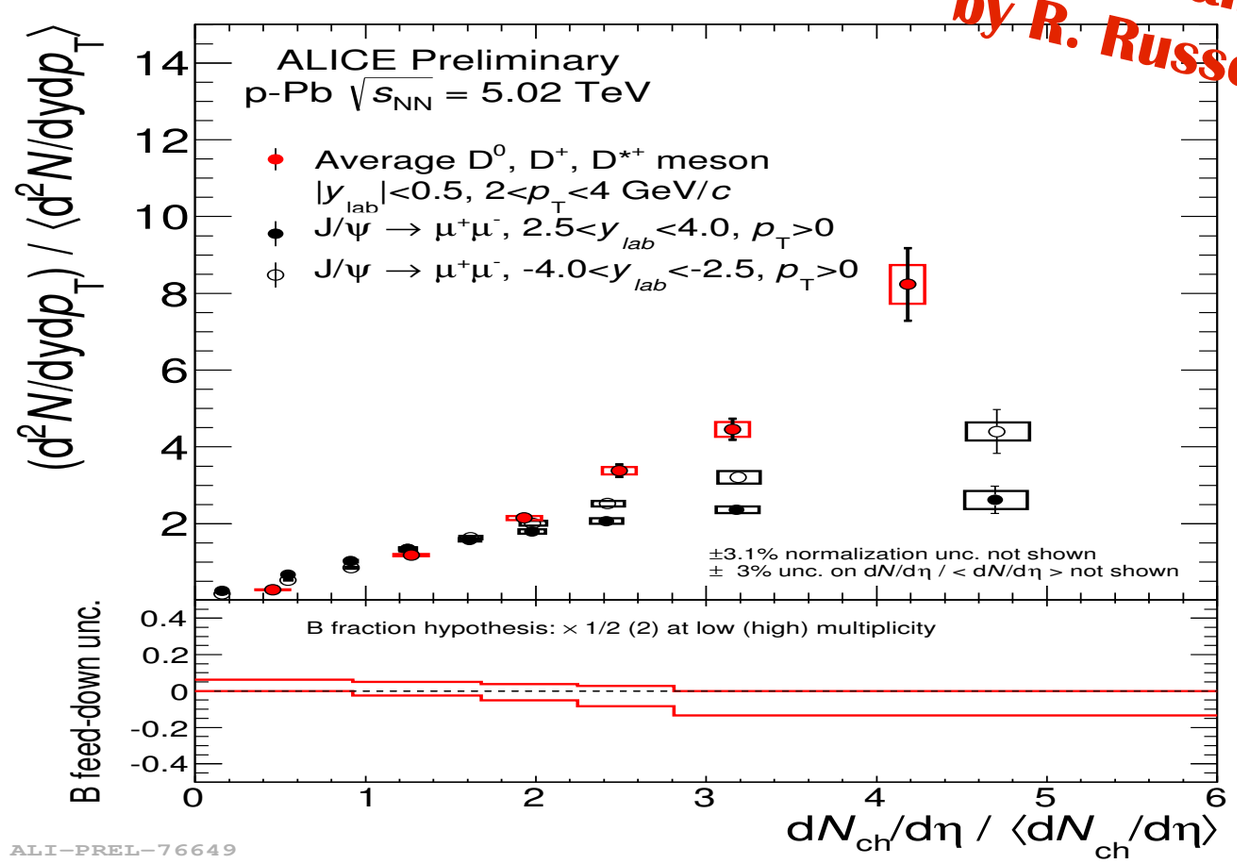


- **Strong increase** of relative J/ψ yields at forward and backward rapidity with relative multiplicity
- At backward rapidity similar behavior as found in pp collisions, deviation at forward rapidity

RELATIVE YIELD vs MID-y RELATIVE MULTIPLICITY

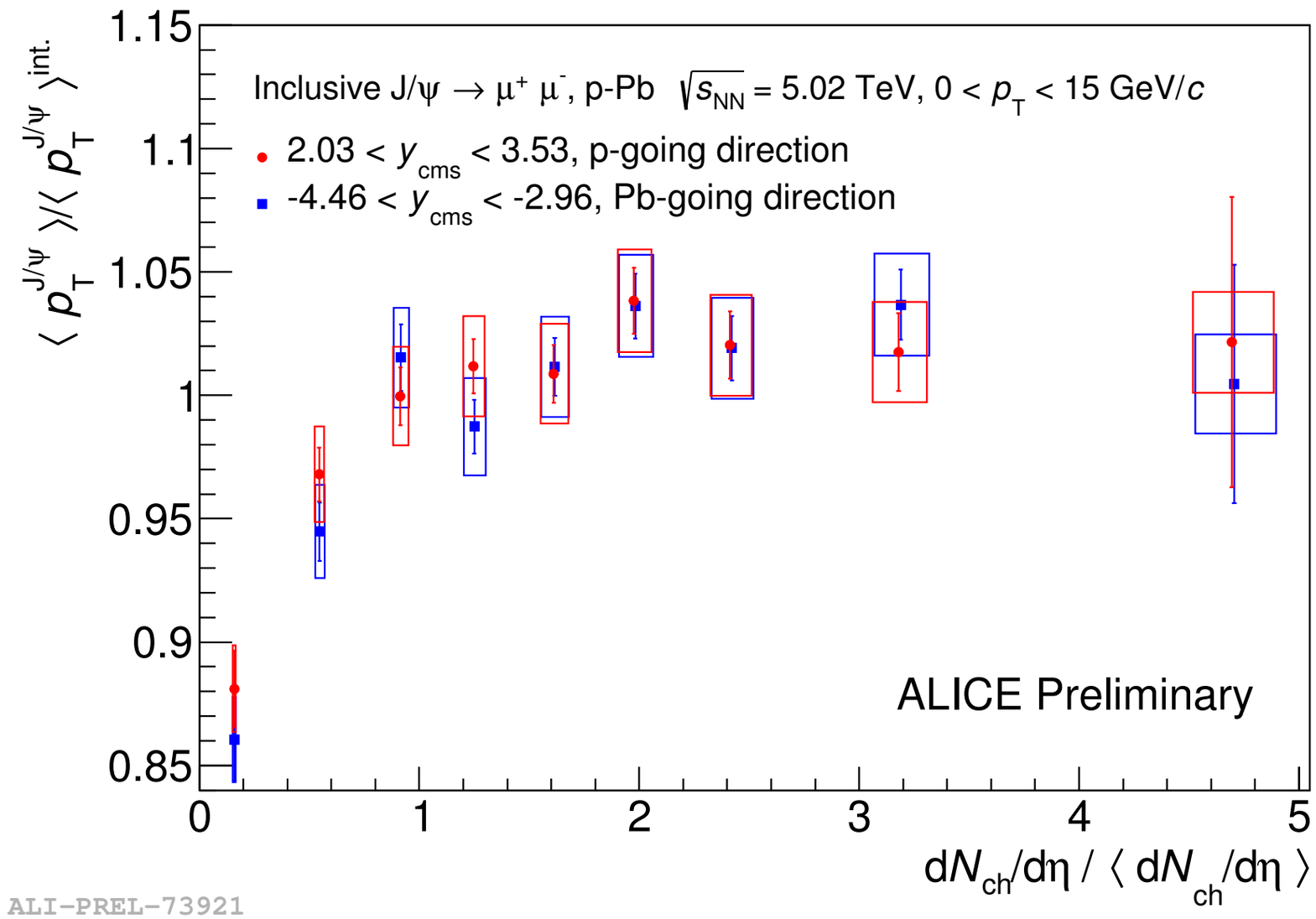


See HF talk by R. Russo



- **Strong increase** of relative J/ψ yields at forward and backward rapidity with relative multiplicity
- At backward rapidity similar behavior as found in pp collisions, deviation at forward rapidity
- D meson relative yield at central rapidity shows also a **strong increase**

<p_T> vs MID-y RELATIVE MULTIPLICITY



- The relative J/ψ <p_T> increases with the mid-rapidity relative event multiplicity and then saturates beyond $dN_{ch}/d\eta/\langle dN_{ch}/d\eta\rangle$ ~1.5
- The same behavior is observed for forward and backward rapidity J/ψ

CONCLUSIONS

ALICE has performed a measurement of J/ψ production in p-Pb collisions at backward, central and forward rapidity:

- Significant suppression at mid and forward rapidity while no suppression at backward rapidity. Fair agreement with shadowing with/without coherent energy loss models.

- R_{pPb} vs p_T shows suppression at mid and forward rapidity for low p_T. Good agreement with available models, except at forward rapidity and low p_T.

- Simple extrapolation of CNM effects from p-Pb to Pb-Pb collisions shows a strong suppression at large p_T and hints of recombination at low p_T.

- Q_{pPb} vs event activity studied for the first time. No appreciable nuclear effects at low event activity. Suppression at forward rapidity and enhancement at backward rapidity for increasing event activity.

- Relative yields at forward and backward rapidity show a strong increase with charged particle multiplicity. Similar behavior as in pp.

- Relative J/ψ $\langle p_T \rangle$ increases at low multiplicity and saturates.

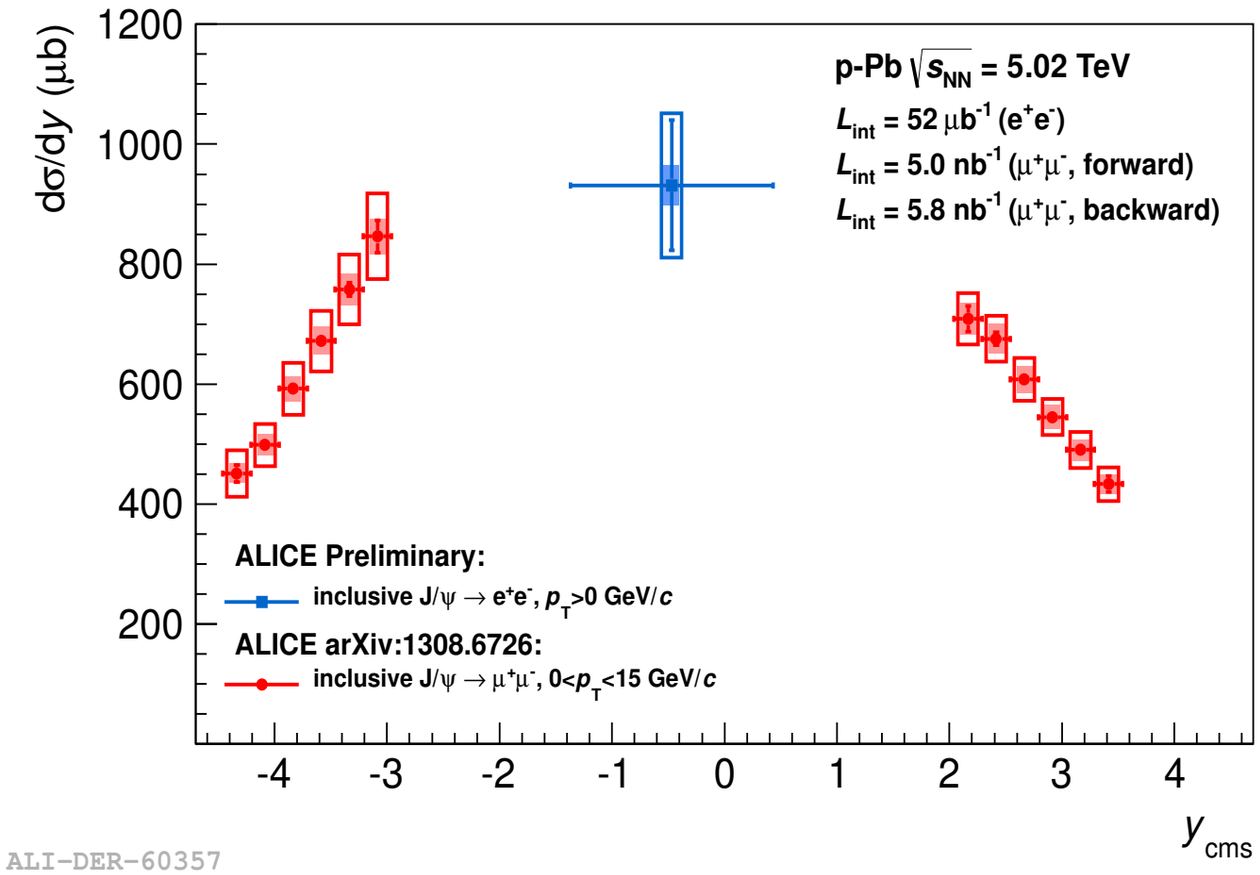
THANK YOU FOR YOUR ATTENTION

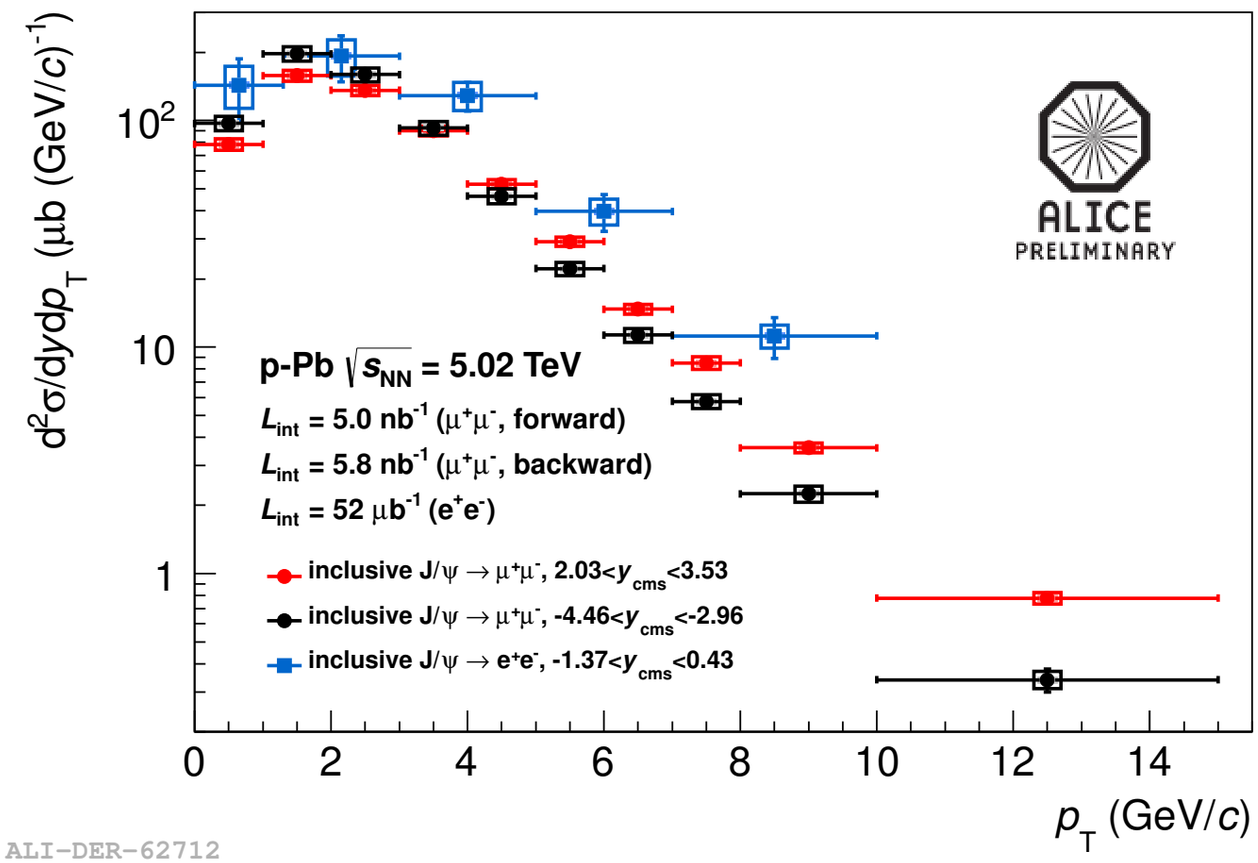
BACKUP

DIFFERENTIAL CROSS SECTION

$$\frac{d^2\sigma}{dydp_T} = \frac{Y_{J/\psi\to\mu^+\mu^-(e^+e^-)}(\Delta p_T, \Delta y)}{BR(J/\psi \to \mu^+\mu^-(e^+e^-)) \times \Delta p_T \times \Delta y} \times \sigma_{MB}$$

$$Y_{J/\psi\to\mu^+\mu^-(e^+e^-)}(\Delta p_T, \Delta y) = \frac{N_{J/\psi\to\mu^+\mu^-(e^+e^-)}(\Delta p_T, \Delta y)}{N_{MB} \times A\epsilon}$$



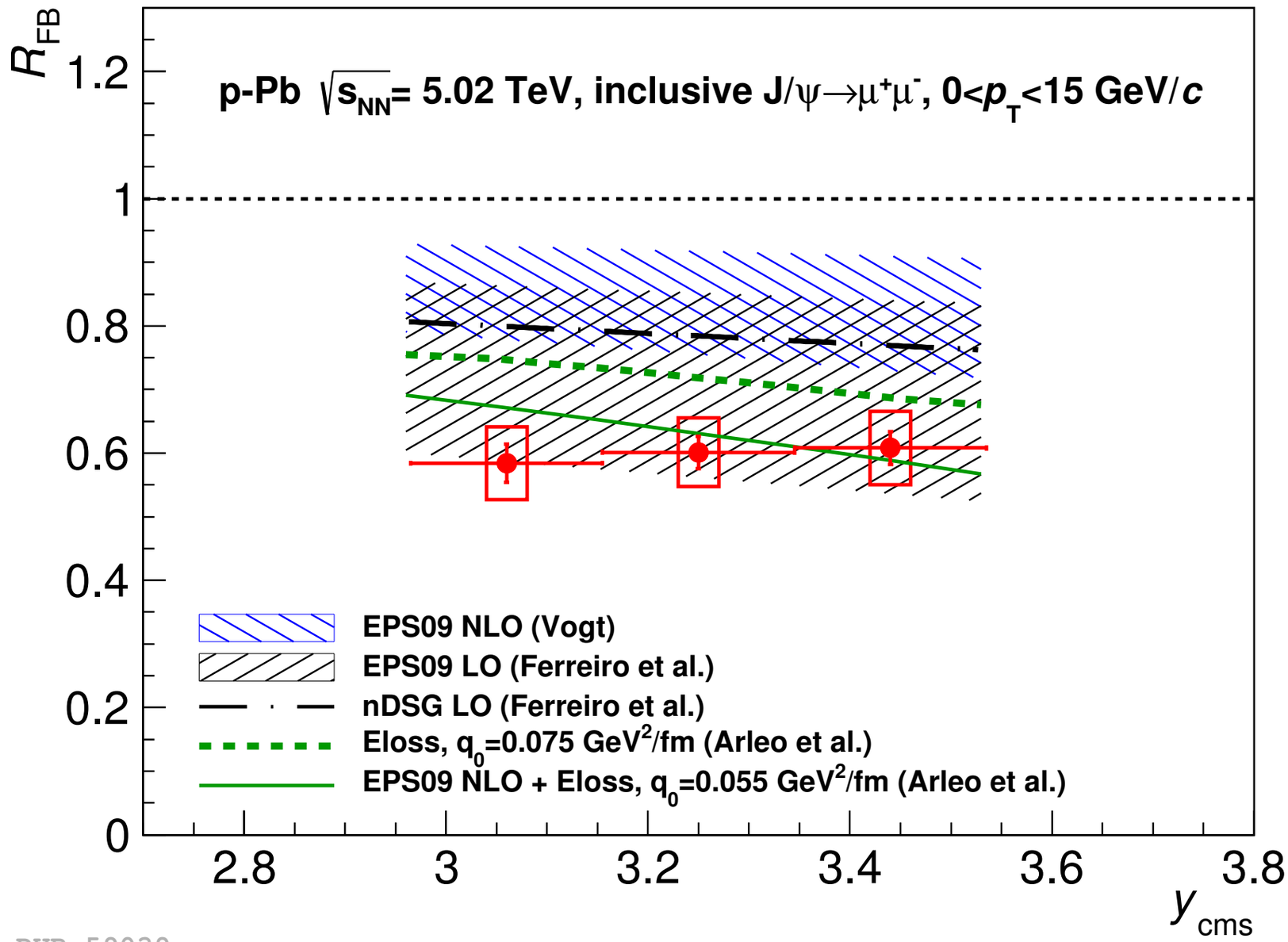


Cross-sections are higher in the backward rapidity region than in the forward region

$\langle p_T \rangle_{0<pt<15} = 2.77 \pm 0.01^{stat.} \pm 0.02^{syst.}$ GeV/c

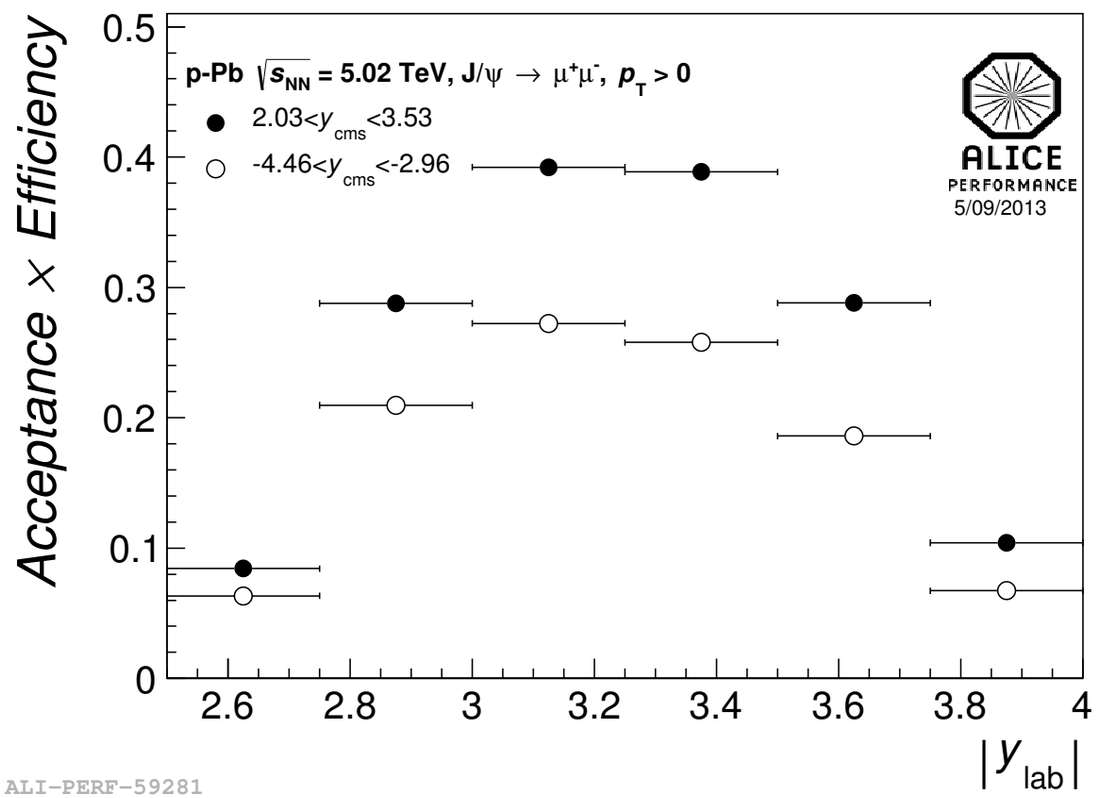
$\langle p_T \rangle_{0<pt<15} = 2.47 \pm 0.01^{stat.} \pm 0.02^{syst.}$ GeV/c

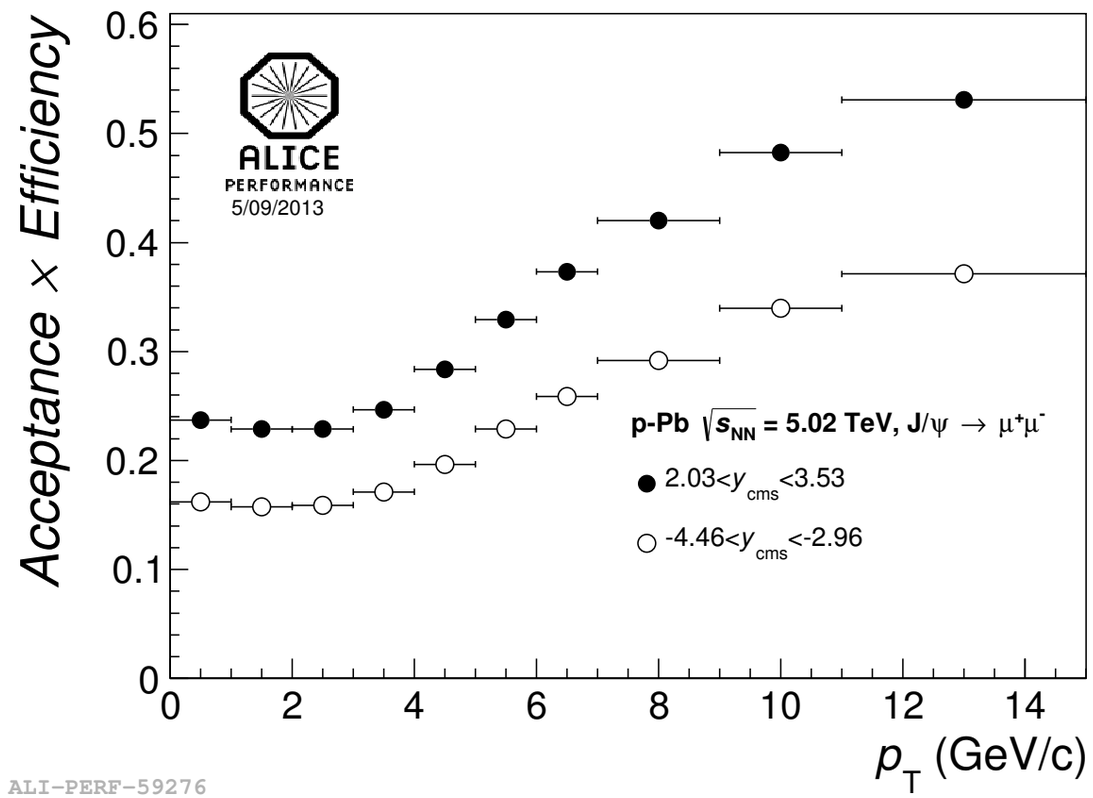
R_{FB} vs RAPIDITY



ALI-PUB-59039

ACCEPTANCE × EFFICIENCY





R_{pPb} UNCERTAINTIES: MIDRAPIDITY

Systematic uncertainties

	p_T-integrated	p_T-differential
S. Extraction & PID uncorr. between p_T bins	11.1 %	10 - 20 %
Tracking efficiency uncorr. between p_T bins	6 %	6 %
MC kinematics	3 %	negligible
$\langle T_{pPb} \rangle$ fully corr. wrt. forward and backward results	3.4 %	-
σ_{pPb}^{MB} corr between p_T bins and wrt forward result	-	3.4 %
$\sigma_{pp}^{J/\psi}$ 16.6% corr. between p_T bins	16.6 %	17 - 27 %

UNCERTAINTIES: FORWARD/BACKWARD RAPIDITY

Systematic uncertainties (not exhaustive, just indicative)

	p-going direction	Pb-going direction
Tracking Efficiency	4 %	6 %
Trigger Efficiency	2.8 % (2-3.6%****)	3.2 % (2-3.6%***)
Signal extraction	1.3 % (1 - 4 %)	1.2 % (1.2 - 6.7 %)
MC input	1.5 % (0.1 - 3 %)	1.5 % (0.1 - 4.2 %)
Matching efficiency	1 %	1 %
F	1 %	1 %
$\sigma_{pp}^{J/\psi}$ **	4.3 % (3.1 - 6.0 %)	4.6 % (1.5 - 13.4 %)
$\langle T_{pPb} \rangle$ ***	(1.5-9.5 %)	(1.5-9.5 %)
σ_{pPb}^{MB} *	3.2 %	3 %
$\sigma_{pp}^{J/\psi}$ **	3.7 % (2.7 - 9.2 %)	3.1 % (1.2 - 8.3 %)
Pile-up***	2 %	2 %
B.R	1 %	
$\langle T_{pPb} \rangle$ **	3.6 %	
$\sigma_{pp}^{J/\psi}$ **	5.5 %	

Uncorrelated (in p_T/y and betw. systems)
Partially correlated (c. in p_T/y, uc. betw. systems)
Correlated (fully correlated)
Note: The sharing of the uncertainties may change slightly in event activity bins depending on the quantities plotted.

* for $\sigma_{pPb}^{J/\psi}$ only
** for R_{pPb} and Q_{pPb} only
*** for Q_{pPb} and $\sigma_{pPb}^{J/\psi}$ in ev. act bins only
**** for p_T bins only

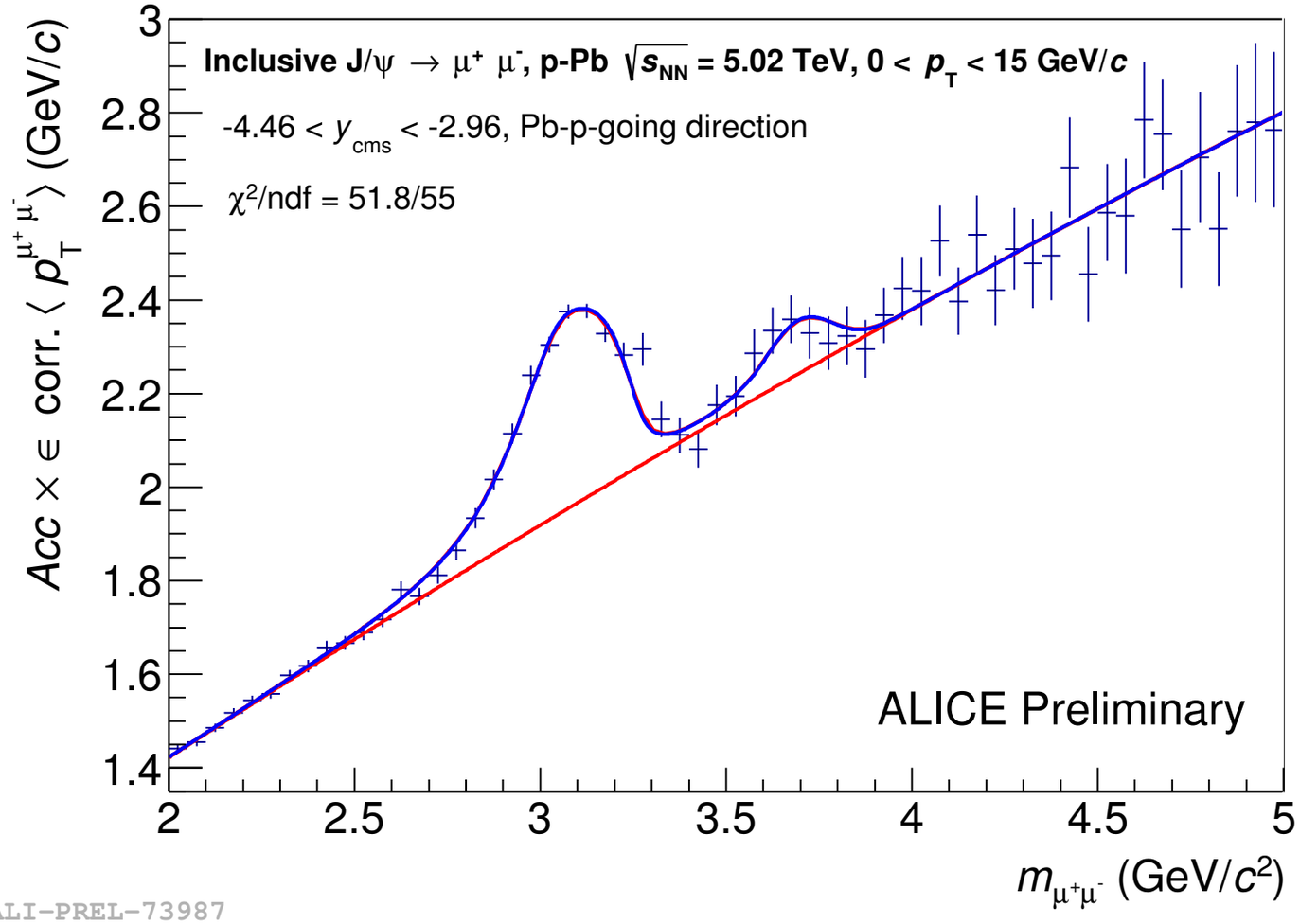
() min-max values in p_T, y or ZN-bins

RELATIVE YIELD AND <p_T> vs MID-y RELATIVE MULTIPLICITY ANALYSIS STRATEGY

J/ψ signal extraction and <p_T> extraction from J/ψ *Acc* × ε (p_T,y) corrected spectra in multiplicity bins

Yield extraction procedure similar to previous analysis, for <p_T > a different method used:

$$< p_T >^{\mu^+\mu^-}(M_{\mu^+\mu^-}) = \alpha^{J/\psi}(M_{\mu^+\mu^-}) \times < p_T >^{J/\psi} + \alpha^{\psi'}(M_{\mu^+\mu^-}) \times < p_T >^{\psi'} + (1 - \alpha^{J/\psi}(M_{\mu^+\mu^-}) - \alpha^{\psi'}(M_{\mu^+\mu^-})) \times < p_T >^{bkg}$$



Based on Signal-Background ratio:

$$\alpha(M_{\mu^+\mu^-}) = \frac{S(M_{\mu^+\mu^-})}{S(M_{\mu^+\mu^-}) + B(M_{\mu^+\mu^-})}$$

$$< p_T >^{J/\psi} \rightarrow constant$$

$$< p_T >^{\psi'} \rightarrow constant$$

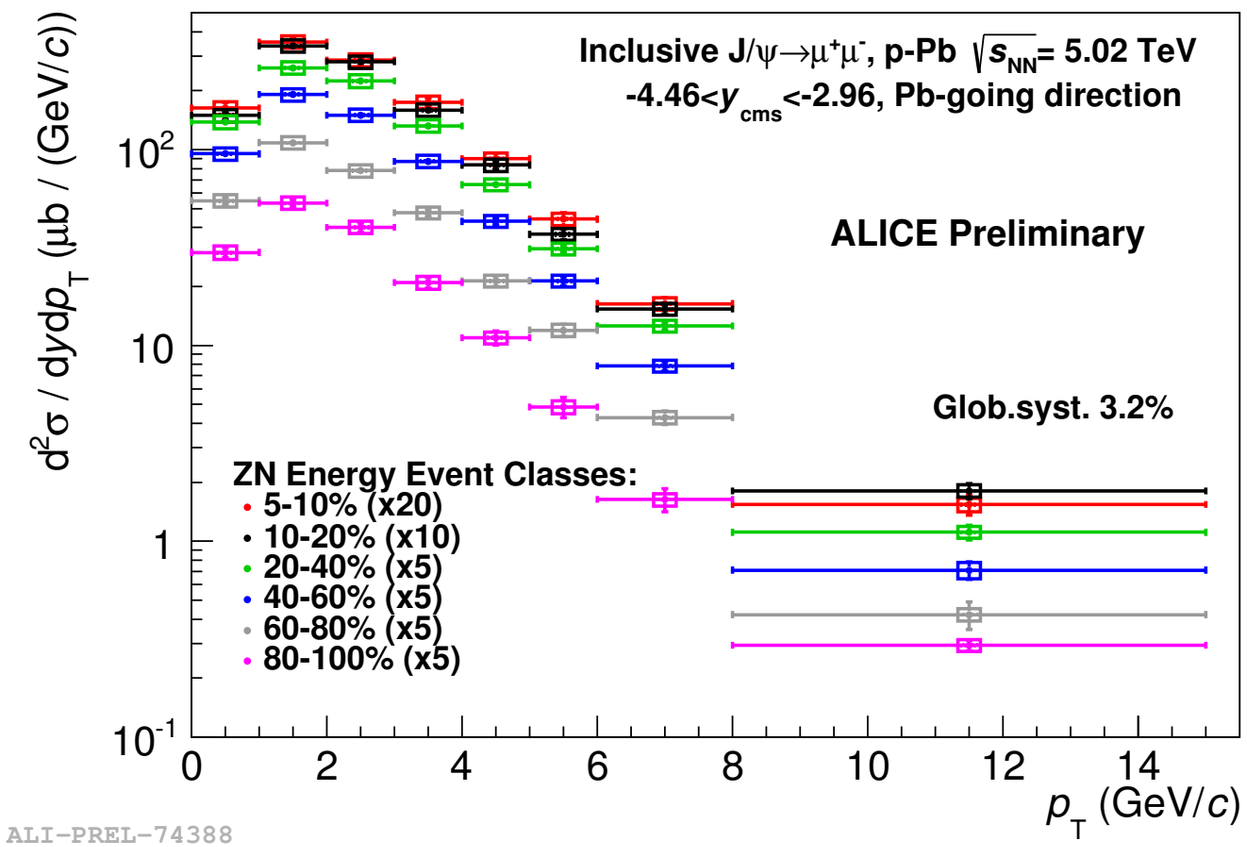
$$< p_T >^{bkg} = pol2$$

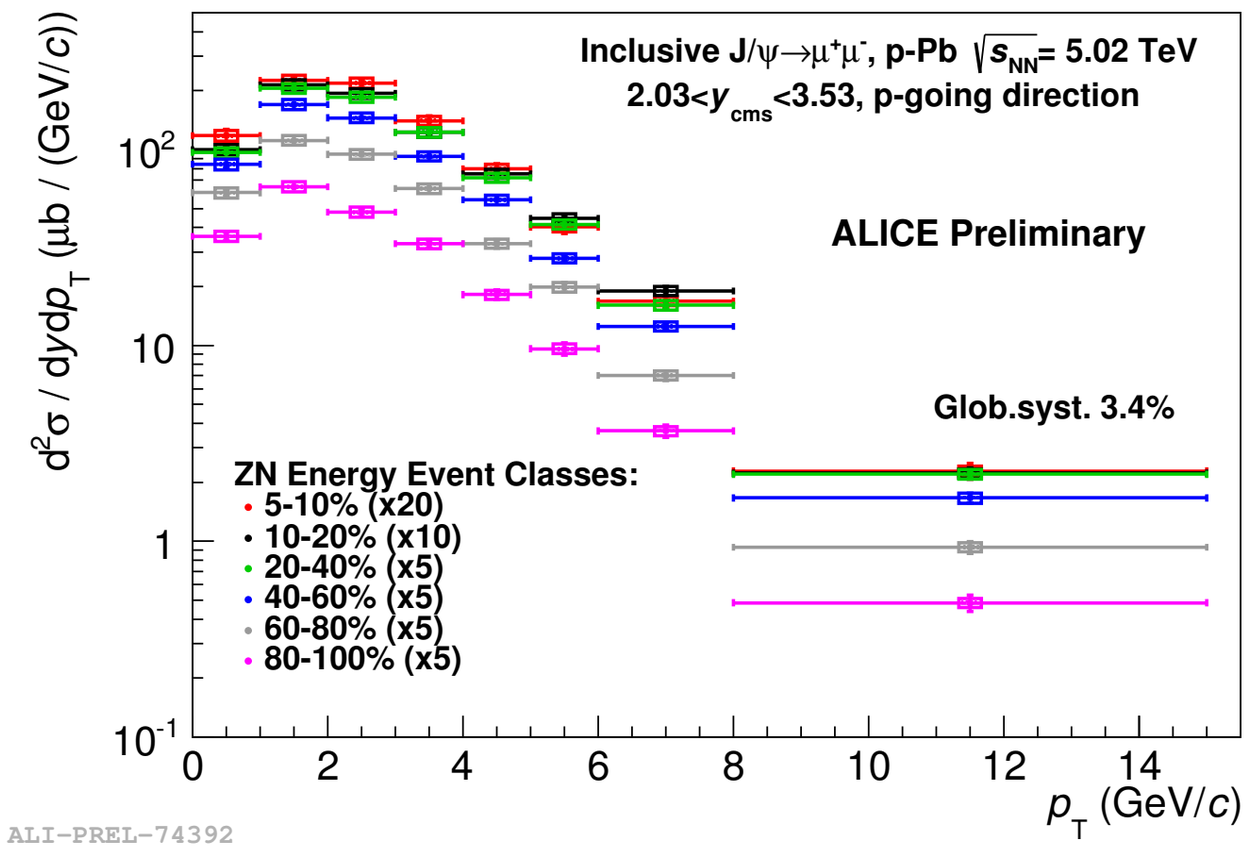
RELATIVE YIELD AND <p_T> vs MID-y RELATIVE MULTIPLICITY UNCERTAINTIES

Only uncorrelated systematic uncertainties remains at first order in relative quantities

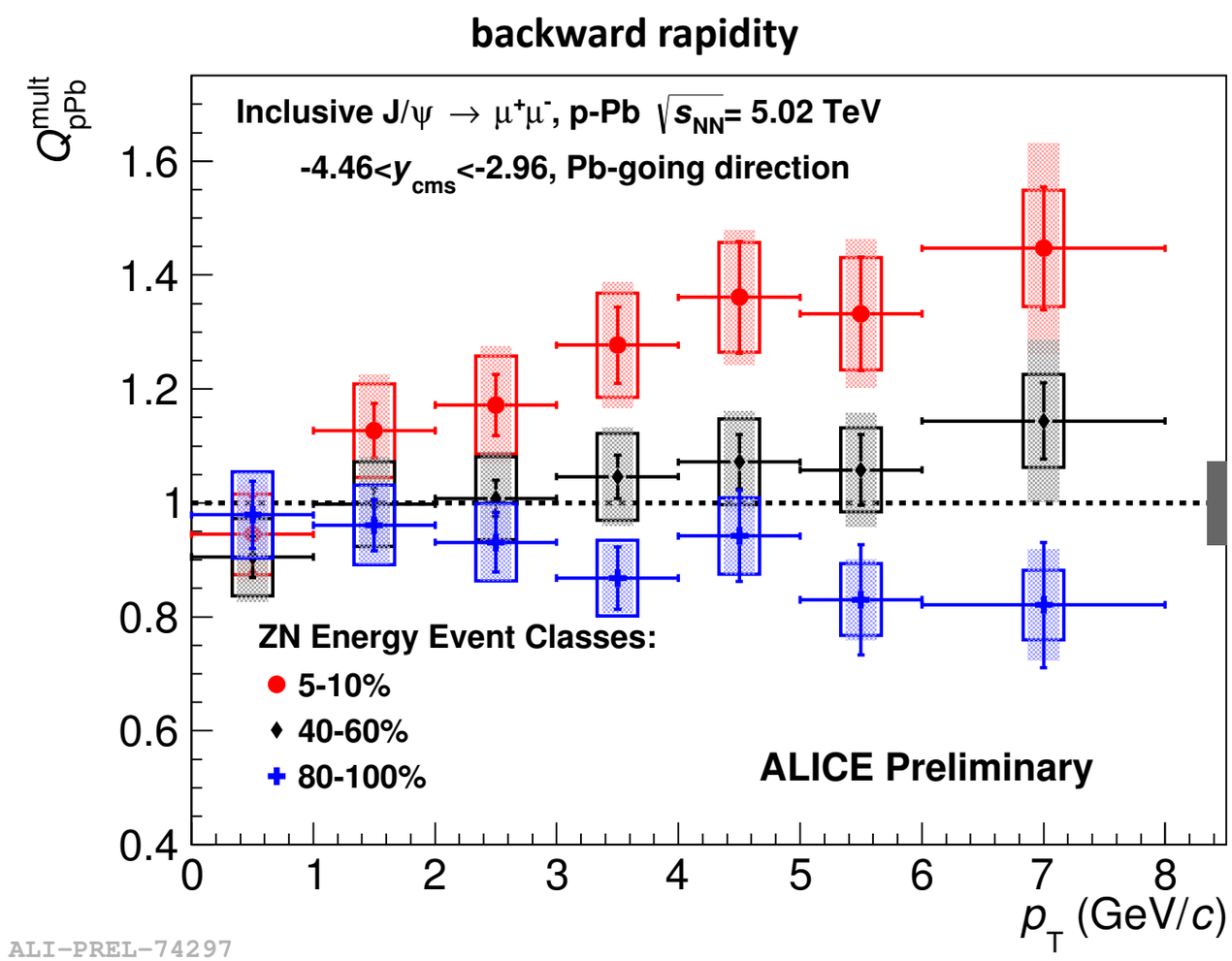
	Forward-y	Backward-y
Extraction method $N_{J/\psi}^{bin}$	1.5-7 %	1.5-7 %
S. Extraction $N_{J/\psi}^{bin}/N_{J/\psi}$	1.5-3.3 %	1.5-4.6 %
<p_T> MC input	2 %	2 %
Extraction <p_T>/<p_T>$^{int.}$	0.1-0.4 %	0.1-1.2 %
F	1-7 %	1-4%
<$dN_{ch}/d\eta$>	3.9%	3.9%
Pile up	1-4%	1-2%

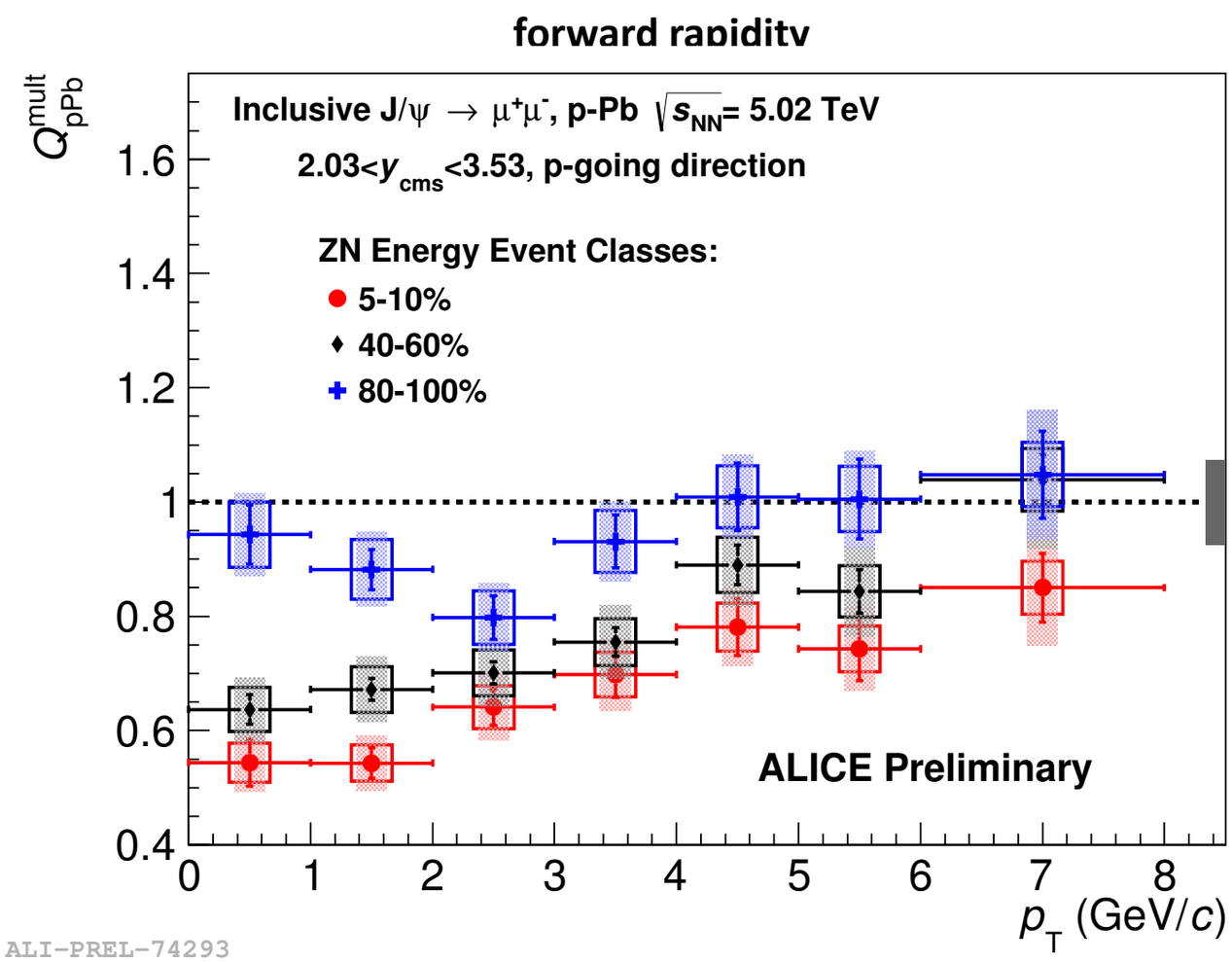
p_T-DIFFERENTIAL CROSS SECTION EVENT ACTIVITY DEPENDENCE





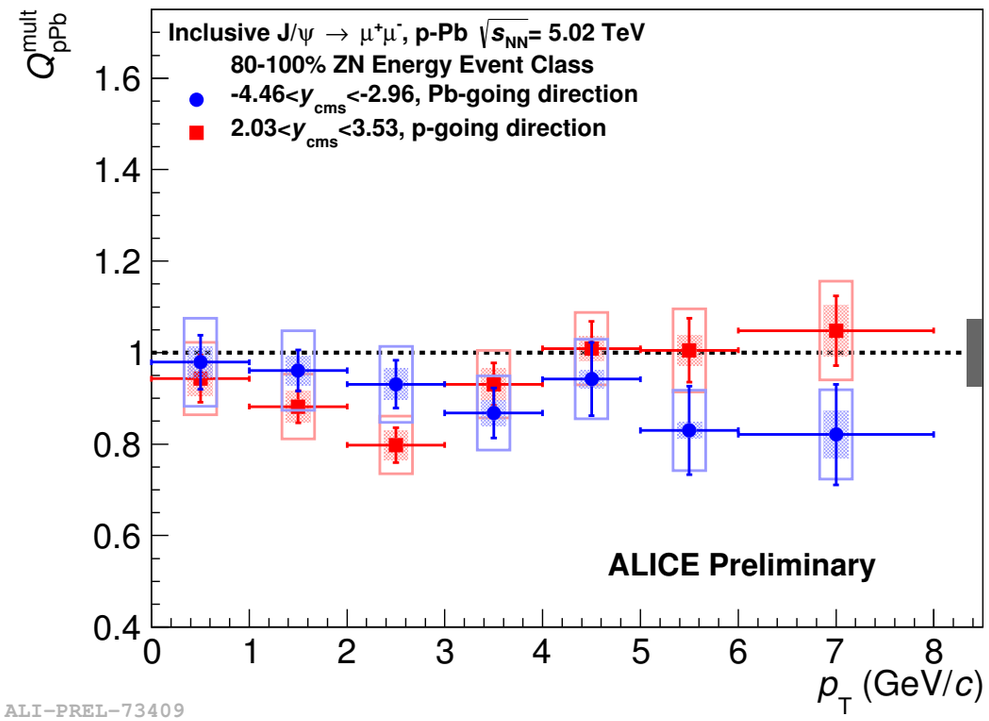
Q_{pPb} vs p_T : EVENT ACTIVITY DEPENDENCE

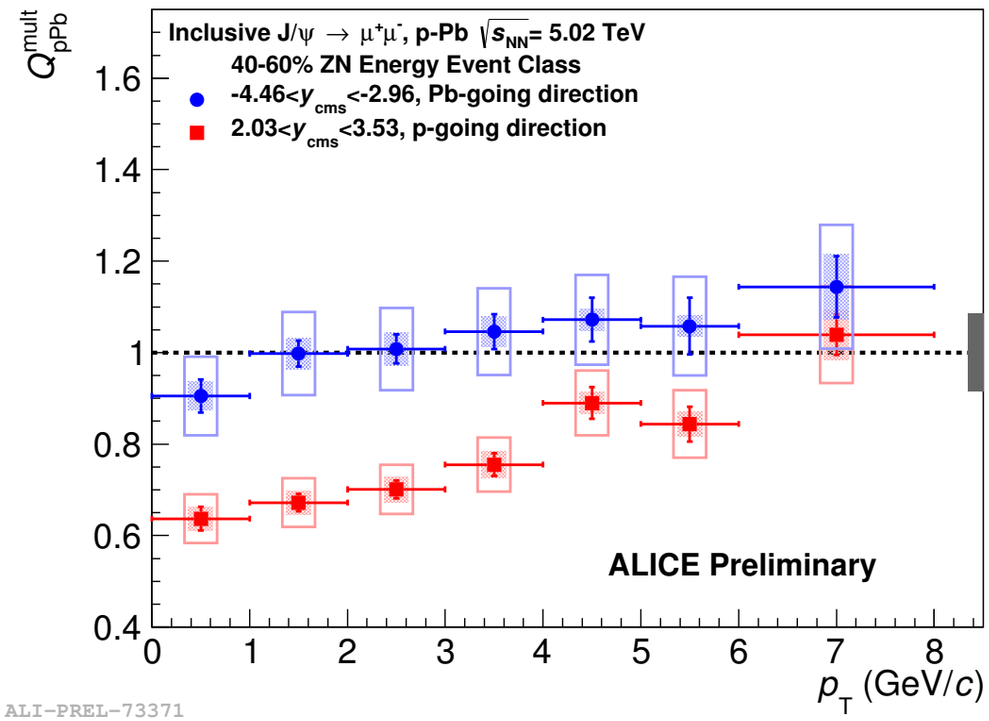


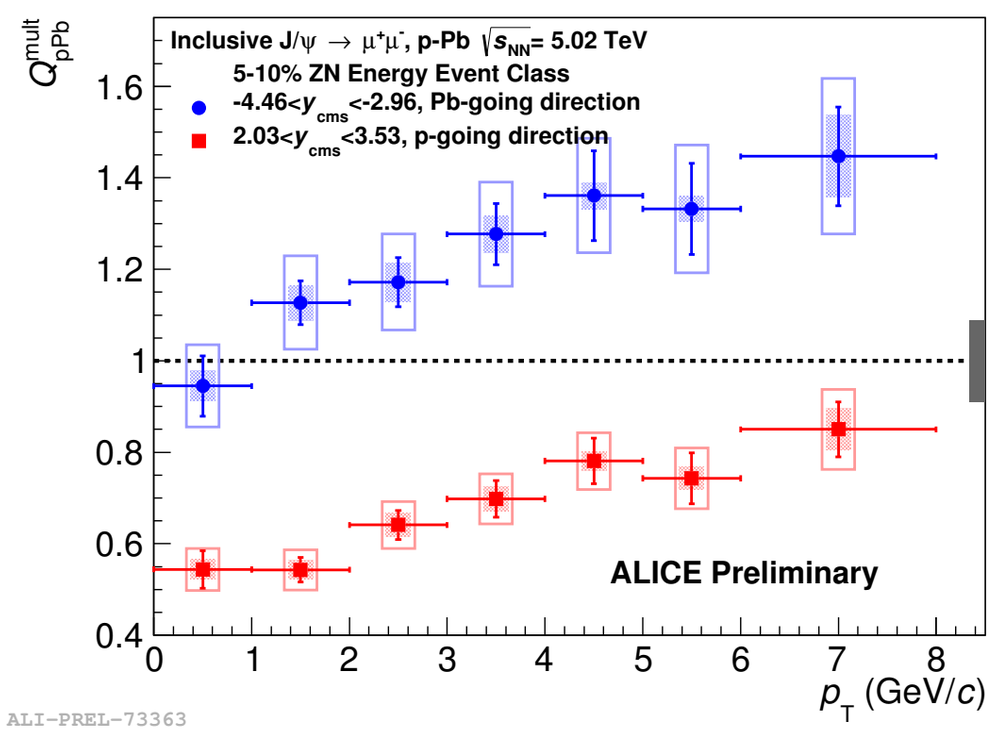


- **Increase** of Q_{pPb} for increasing event activity at **backward** rapidity. A p_T dependence is also observed, showing a stronger enhancement at high p_T
- **Decrease** of Q_{pPb} for increasing event activity at **forward** rapidity. A p_T dependence is also observed, showing stronger suppression at low p_T

Q_{pPb} vs p_T : EVENT ACTIVITY DEPENDENCE

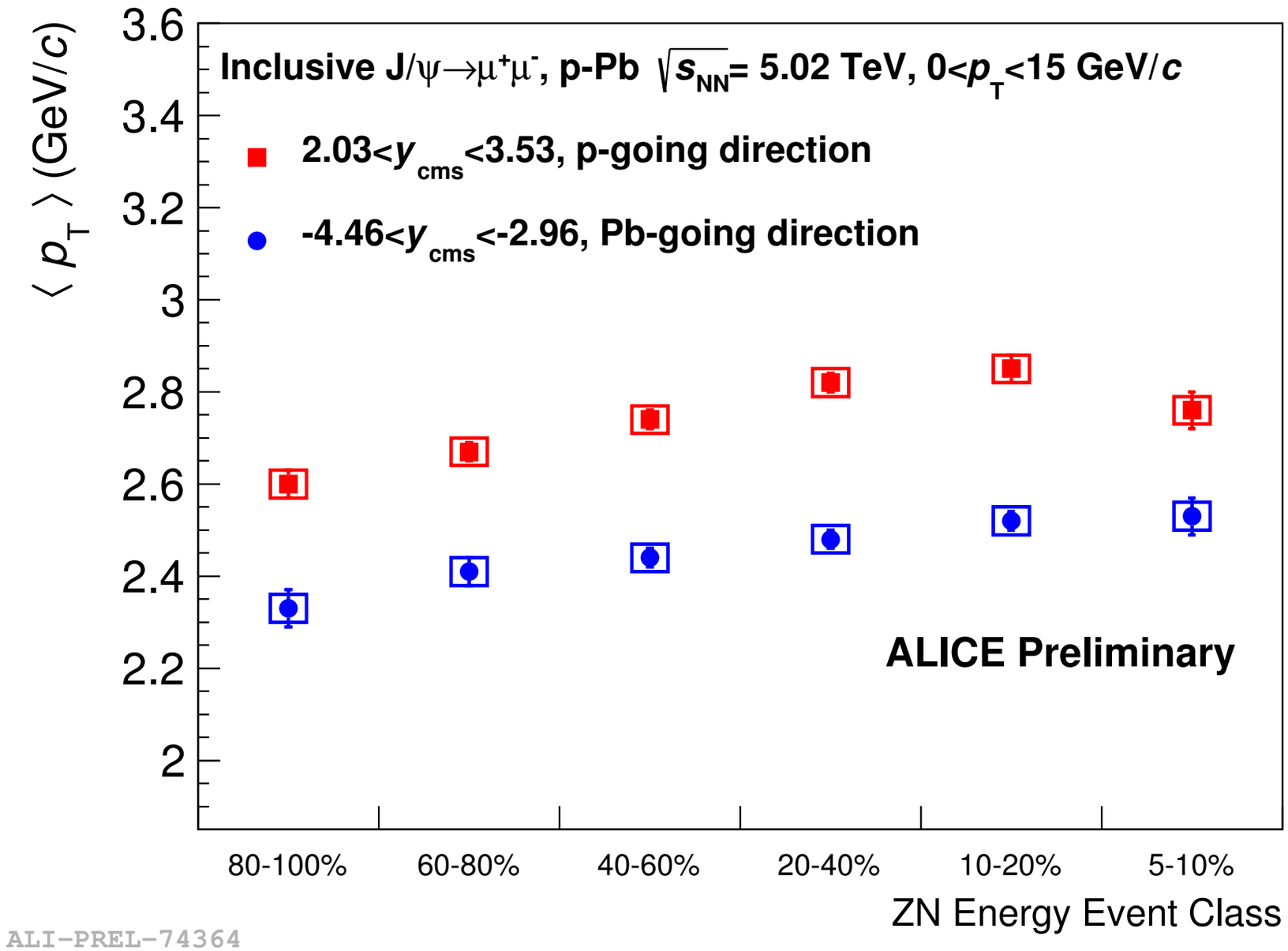






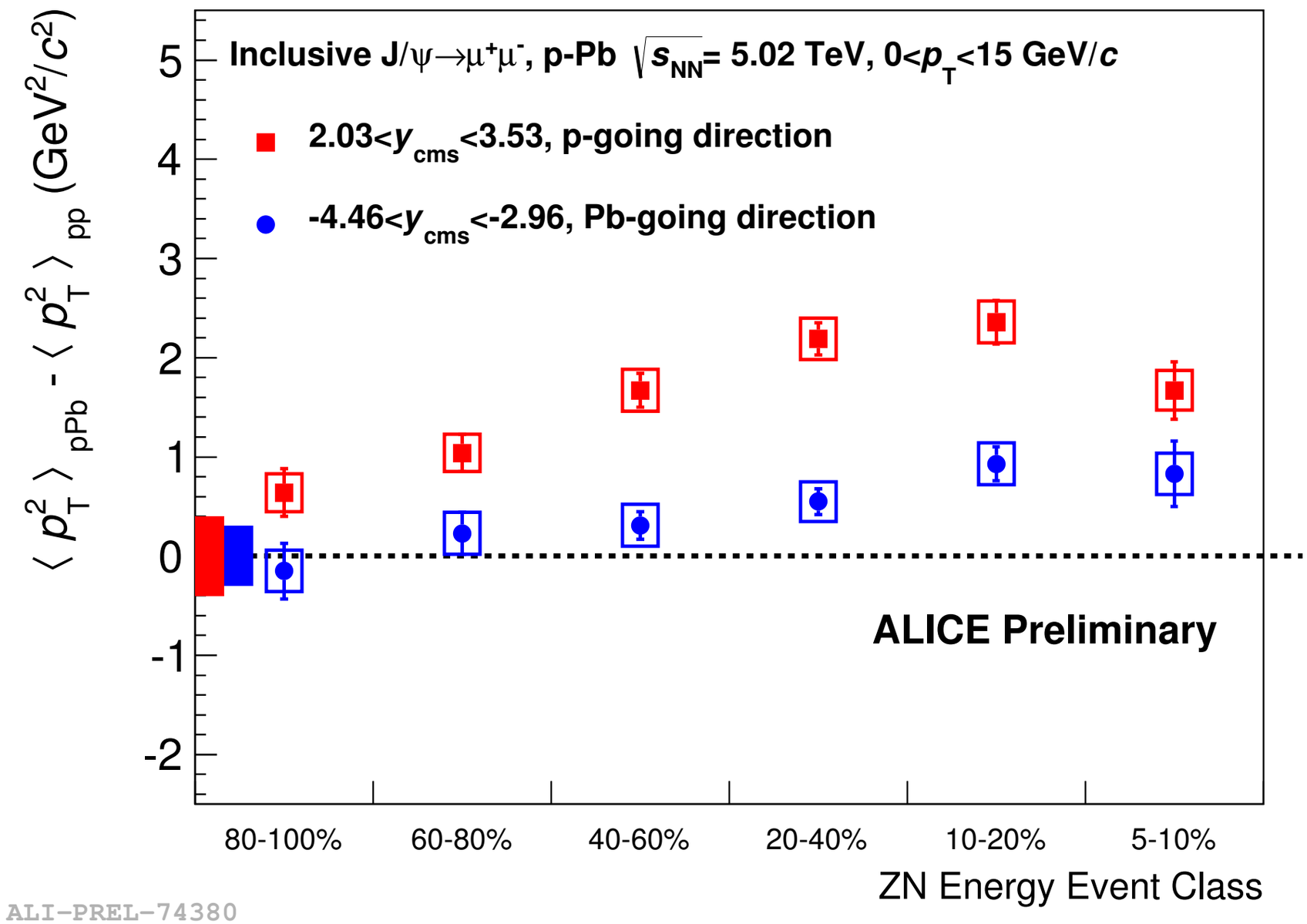
- For increasing event activity the difference between forward and backward rapidity results becomes much stronger

<p_T> vs EVENT ACTIVITY



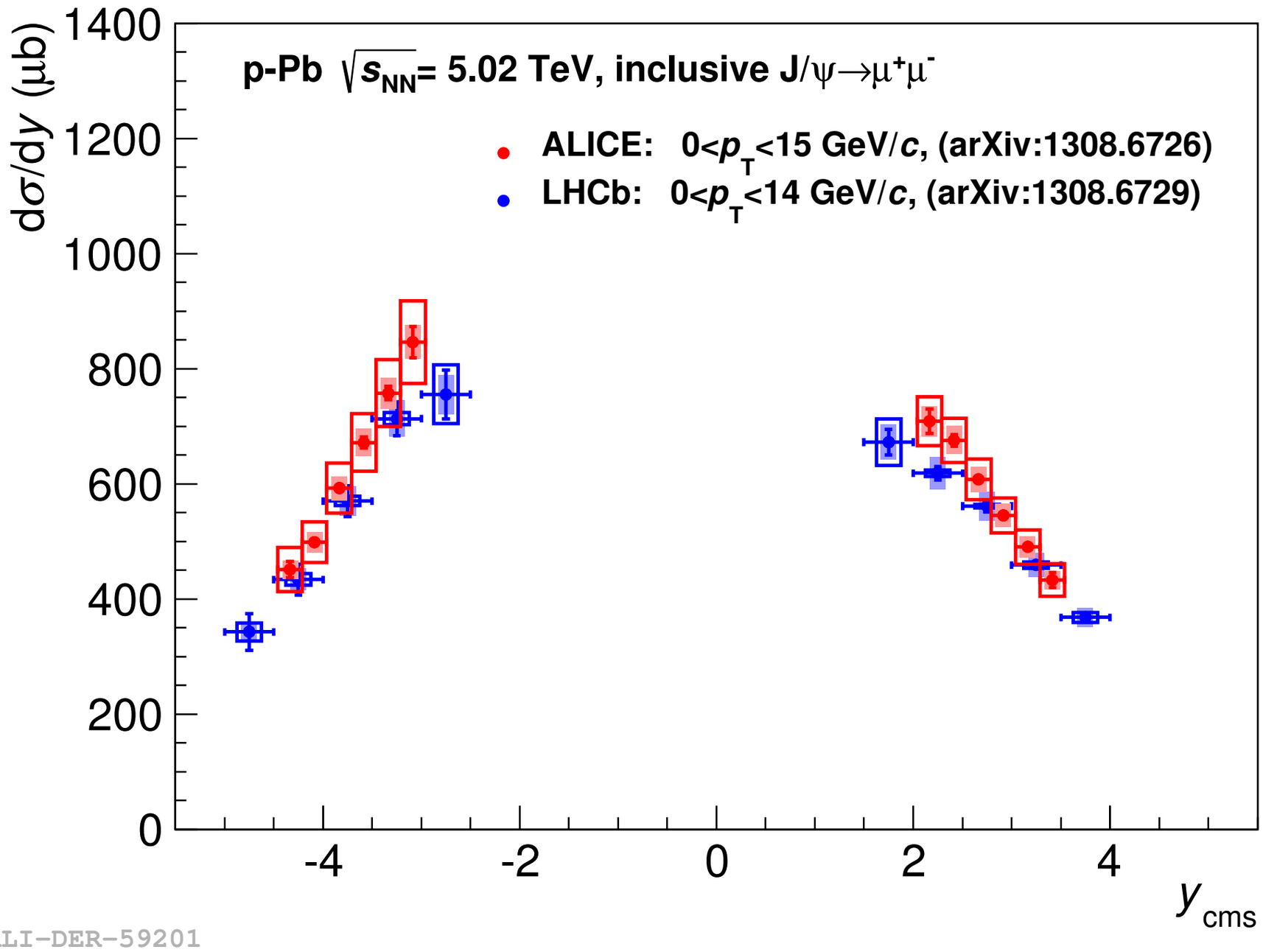
- <p_T> shows an increase with the event activity at forward and backward rapidity
- <p_T> is systematically higher at forward than at backward rapidity

$\langle p_T \rangle$ BROADENING vs EVENT ACTIVITY



- $\Delta\langle p_T^2\rangle^{J/\psi}$ compatible with pp value for the lowest energy event class
- $\Delta\langle p_T^2\rangle^{J/\psi}$ increases with energy event class
- $\Delta\langle p_T^2\rangle^{J/\psi}$ values systematically higher at forward than at backward rapidity

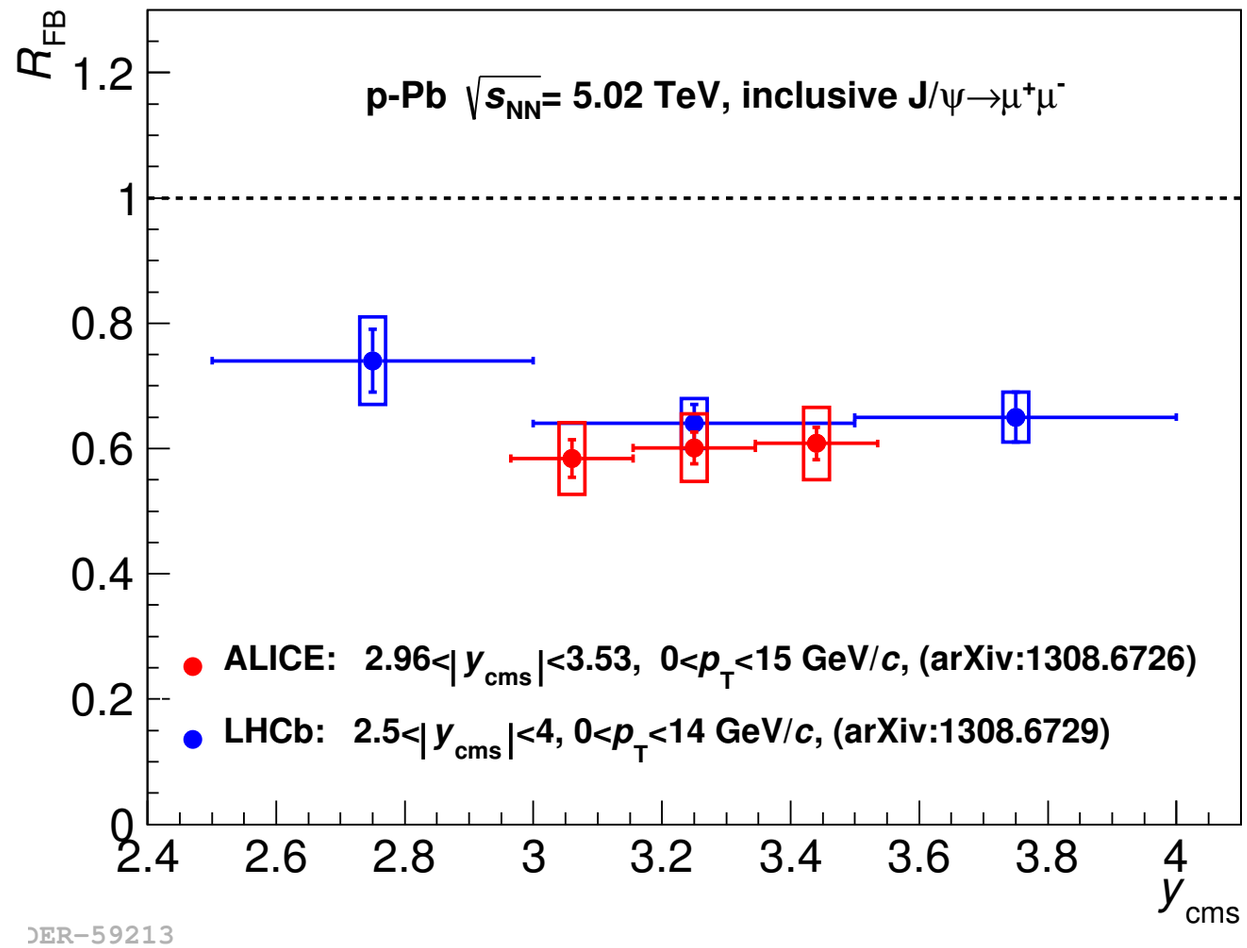
ALICE AND LHCb COMPARISON

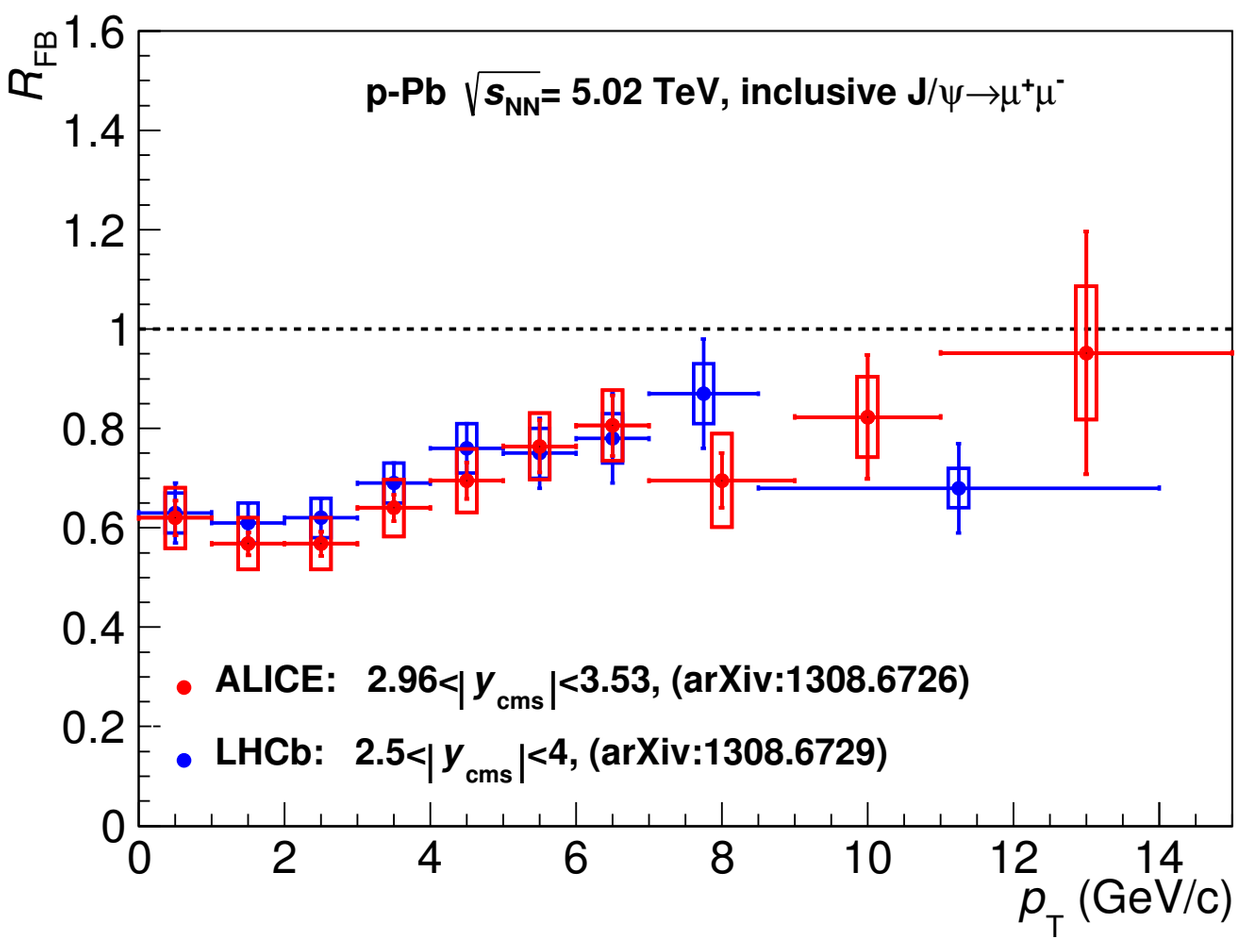


- Results in good agreement within uncertainties

ALICE AND LHCb COMPARISON

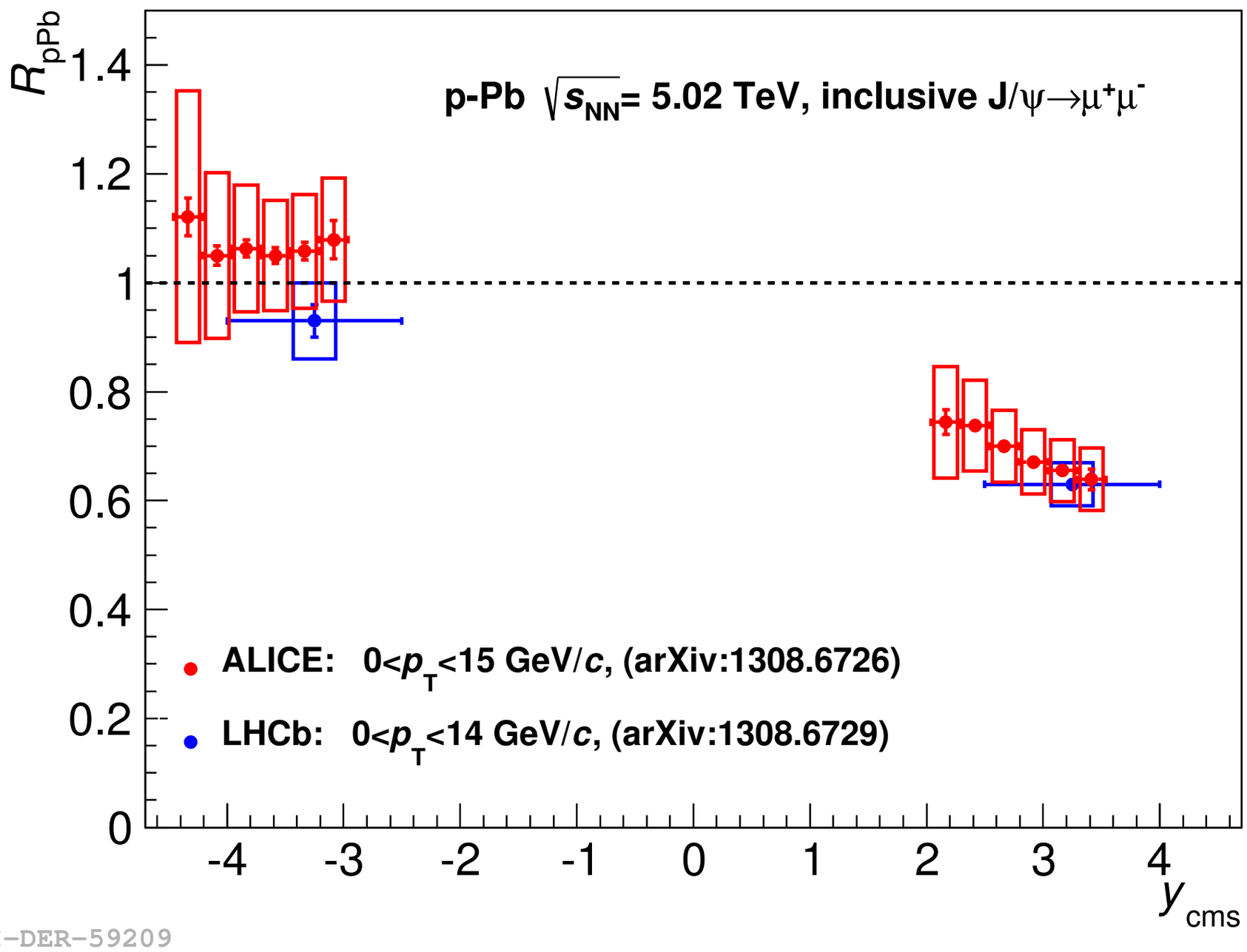
- Results in good agreement within uncertainties





- Results in good agreement within uncertainties

ALICE AND LHCb COMPARISON



- Results in good agreement within uncertainties